Final Report for Period: 07/2009 - 06/2010 **Submitted on:** 05/24/2010
Principal Investigator: Mayewski, Paul A. **Award ID:** 0636506
Organization: University of Maine
Submitted By:
Mayewski, Paul - Principal Investigator
Title:
Collaborative Proposal: 2000+ Year Detailed, Calibrated Climate Reconstruction from a South Pole Ice Core Set in an Antarctic - Global Scale Context

Project Participants

Senior Personnel

Name: Mayewski, Paul
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Kreutz, Karl
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Kurbatov, Andrei
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Dunbar, Nelia
Worked for more than 160 Hours: Yes
Contribution to Project:
Examination of volcanic tephra found in the ice core.

Name: Aizen, Vladimir
Worked for more than 160 Hours: Yes
Contribution to Project:
Laser particle analysis for the core.

Post-doc

Graduate Student

Name: Korotkikh, Elena
Worked for more than 160 Hours: Yes
Contribution to Project:
PhD student supported by this grant. This project forms the basis for her PhD dissertation. She will conduct all sample processing, participate in glaciochemical analyses, and develop resulting papers.

Name: Sneed, Sharon
Worked for more than 160 Hours: Yes
Contribution to Project:
Sharon will use some of the data from this project for her PhD dissertation. She is also in charge of generating soluble io data for this ice core.

Undergraduate Student

Technician, Programmer

Name: Handley, Mike

Worked for more than 160 Hours: Yes

Contribution to Project:

Mike is in charge of the trace metal analyses for this ice core.

Other Participant

Research Experience for Undergraduates

Organizational Partners

New Mexico Technical University

Provide volcanic record and tephra analysis expertise.

University of Idaho

Provide particle counter for analysis.

Other Collaborators or Contacts

We plan to compare the South Pole high resolution 2ka record being developed in this project with a record from Mt. Moulton that covers the Eemian to yield the first high resolution, multi-variate comparison between late Holocene and late Eemian climate in the Southern Hemisphere. Results from the Mt. Moulton Eemian record are presented in this report. The Mt. Moulton record was collected in collaboration with N. Dunbar (New Mexico Tech - involved in this proposal) as well as T. Sowers (Penn State University).

Activities and Findings

Research and Education Activities:

Year 1:

Elena Korotkikh and Andrei Kurbatov of the Climate Change Institute (CCI)at the University of Maine and Jennifer Kendall from the University of Idaho (UI) spent several weeks working on the integration of the CCI continuous melting system (CMS) and the UI 'Klotz' particle counter in the CCI freezers, CCI CMS laboratory and the CCI Tephra/Particles laboratory.

They tested the ion chromatography (IC) and ion coupled plasma mass spectrometer (ICPMS)line coming from the CMS with the particle counter inline to see how well the system works using South Pole core samples from an old South Pole core (1995). The IC and ICPMS line testing was done to avoid possible contamination by the particle counter instrument. Discrete sampling and melted samples from the SPRESSO South Pole core (this project) were compared for additional calibration. The training has allowed Kendall (UI) to start to build a CMS with particle counter at the UI ice core laboratory.

In addition CCI Handley and Sneed have spent considerable time continuing to expand the measurement capability of the ICPMS instrument that will yield trace element values from the South Pole record. The East Antarctic plateau has exceedingly low trace element levels necessitating highly stringent contamination and measurement procedures. The CCI ICPMS routinely provides ppq level results. However, to expand the array of trace elements available at the ppq level and to deliver ppq level time series where variability in the signal is definitively natural rather than laboratory induced requires extensive testing and demonstration. Unlike some continuous flow ice core melting techniques that do not provide samples for replicate analyses the CCI CMS system does provide replicate samples, hence the opportunity to fine tune our sampling and analytical systems. Much of the fine tuning for the ICPMS analyses is conducted on Mt Moulton ice since very large volume samples are available from this trench record.

Year 2:

Annual layer counting of the SPRESSO ice core, based on visual stratigraphy reveals an age of 2167 years before AD 2000 at a depth of 207.057 m (Gow and Meese, pers. comm., 2005).

150 meters of the SPRESSO ice core were melted using the University of Maine continuous melting system yielding an average resolution of 60 ? 110 samples per meter (average ~85 samples per meter). A total of 13,240 co-registered samples were collected each for IC (ion chromatography), ICP MS (inductively coupled plasma sector field mass spectrometry) and MS (mass spectrometer stable water isotope analysis). To put the SPRESSO core sampling in perspective the major ion analysis conducted on the GISP2 core, that revolutionized climate change understanding, involved 10,980 samples covering 110,000 years plus an additional ~5000 samples to add detail to pertinent sections such as the Younger Dryas.

Continuous melting was performed in a Class 100 clean room. Clean suits, booties and polypropylene gloves were worn during melting and ice preparation to prevent contamination of the core. The ends of each ice core were scraped using a pre-cleaned (with DI water from MilliQ-Element system (>18.2 MΩ)) ceramic knife before melting to prevent contamination. DI water was pumped through the entire melter system between melting sessions to keep the system clean. DI water blanks were collected before and after every melting session to confirm the system is clean. The melter is made of nickel 270 (>99.99% Ni) to avoid contamination for any species other than nickel. The melting disk has an inner diameter of 26 mm and outer diameter of 65 mm that was specially designed to accommodate the SPRESSO ice core diameter. In order to maintain constant flow the melter head was heated to a constant temperature of 12-18 ?C (depending on ice/firn density).

SPRESSO ice core sample resolution changed from 1.8 to 0.9 cm from the shallow to the deeper part of the core (average 1.12 cm) yielding 8-9 samples per year on average. Samples were collected from the inner and outer parts of the core. To avoid contamination only the inner portion of each core was sampled for IC (each sample 2 ml volume) and ICP-MS analysis (each sample 2 ml volume). The meltwater from the outer part was collected for stable isotope analysis (16 ml sample volume) since this area is not contaminated for stable isotope analysis.

All samples for major ion analyses (IC) were collected into LDPE bottles cleaned by successive soaking and rinsing in DI water, and re-frozen. Samples for stable isotope analysis were collected into dried LDPE vials, and re-frozen. Samples for trace element analysis (ICP-MS) were collected into acid-cleaned (Optima HNO3) LDPE vials. ICP-SMS samples were acidified to 1% with double-distilled HN03 under a class-100 HEPA clean bench and allowed to react with the acid for approximately 1 week before being frozen.

We expect that approximately half of the 13,240 SPRESSO samples will be analyzed for major ions by July. Remaining samples will be completed by the end of this calendar year. During the third year of this project we will also conduct:
(1) Analysis of all stable isotope samples ? these measurements have been moving very slowly due to the age of our mass spectrometer. It has experienced frequent breakdowns. We have (Kreutz et al.) an MRI proposal pending to replace existing MS equipment and update our very elderly ICs.
(2) Analysis of all ICPMS samples.
(3) Melting of the remaining 50 m of the core to allow companion particle measurements. The melter system proposed for companion particle-isotope-chemistry analyses has proven to be far more complicated than expected. However, in the process of developing this system a new, highly innovative component has been added that allows continuous logging of density.

Summary as of May 2010

Methodology.

The South Pole SPRESSO (South Pole Remote Earth Science and Seismological Observatory) ice core was drilled during the 2002-2003 field season, at 89.93?S, 144.39?W, to a depth of 291.26 meters as part of the International Trans Antarctic Science Expedition (ITASE). Annual layer counting based on visual stratigraphy reveals an age of 2167 years before AD 2000 at a depth of 207.057 m (Gow and Meese, pers. comm., 2005). Ice core quality was too poor below this depth and too many sections were missing to produce a coherent record below 200m.

200 meters of the SPRESSO ice core were melted using the University of Maine continuous melting system (Osterberg et al., 2006) yielding a resolution of 60 ? 110 samples per meter. Melting was performed in a Class 100 clean room. Clean suits, booties and polypropylene gloves were worn during melting and ice core preparation to prevent contamination of the core. The ends of each ice core were scraped using a pre-cleaned (with DI water from a MilliQ-Element system (>18.2 MΩ)) ceramic knife before melting to prevent contamination. DI water was pumped through the entire melter system between melting sessions to keep the system clean. DI water blanks were collected before and after every melting session to confirm the system is clean. A nickel 270 (>99.99% Ni) melting disk with an inner diameter of 26 mm and an outer diameter of 65 mm was employed. The melter head was heated to a constant temperature of 12-18 ?C (depending on ice/firn density).

A total of 18,570 co-registered samples were collected each for IC (ion chromatography), ICP MS (inductively coupled plasma sector field mass spectrometry) and stable water isotope analysis. This is a remarkable number of samples. It is equivalent to the number of samples produced by a classical research team for a deep ice core making this core the most highly resolved record ever collected and likely the highest resolution sample co-registered record ever produced. Sample resolution changed from 1.8 to 0.88 cm from the shallow to the deeper part of the core (average 1.12 cm) yielding 8-9 samples per year on average. Samples were collected from the inner and outer parts of the core. To avoid contamination only the inner portion of each core was sampled for IC (each sample 2 ml volume) and ICP-MS analysis (each sample 2 ml volume). The meltwater from the potentially contaminated outer part was collected for stable isotope analysis (16 ml sample volume). Pump speeds for the melter system were 5, 5.2 and 26.5-27.5 cpm for collection of IC, ICP MS and isotopes, respectively..

All samples for major ion analyses (IC) were collected into LDPE bottles cleaned by successive soaking and rinsing in DI water, and re-frozen. Samples for stable isotope analysis were collected into dried LDPE vials, and re-frozen. Samples for trace element analysis (ICP-MS) were collected into acid-cleaned (Optima HNO3) LDPE vials. ICP-SMS samples were acidified to 1% with double-distilled HN03 under a class-100 HEPA clean bench and allowed to react with the acid for approximately 1 week before being frozen.

IC Analyses. To date 4998 samples have been analyzed covering the section 69.56 ? 120.775 m (51.2 m total) corresponding to an age of 925 ? 1455 AD (530 years total). We expect to have the remaining samples analyzed by Dec 2010. The delay was caused by significant breakdowns in our aging IC systems. Our current system is a Dionex ion chromatograph with chemical suppression and conductivity detectors. Anions (Cl-, NO3-, SO4-) were measured using an AS-11 column, 400 μL sample loop, and a Dionex Reagent Free Controller producing a KOH eluent gradient of 1 mM to 8 mM. Two ion chromatographs were paired to a Gilson Liquid Handler autosampler for simultaneous anion and cation analysis. Calibration curves bracket the expected concentration range with correlation coefficients of >0.99. Calibration results were verified using Environment Canada?s ION-92 standard diluted to bring the reported values within range.

ICP MS Analyses. To date 4360 samples have been analyzed covering the section 0.88 ? 72.03 m section for Na, Mg, Ca, Sr, Cd, Cs, Ba, La, Ce, Pr, Pb, Bi, U, As, Al, S, Ti, V, Cr, Mn, Fe, Co, Cu, Zn, Li and K. We recently acquired an auto-sampler system for our ICP MS that allows up to 200 samples per run with a conservatively calculated throughput, allowing for calibration and breakdowns, of ~600 samples per week. We expect to have the remaining samples analyzed by Dec 2010. Our ICP MS analytical output has also been slowed down since we are bringing our second ICP MS on line and wit it our new laser ablation analytical technique. The new LA ICP MS system is supported by a grant from the W.M. Keck Foundation and will allow us to analyze ice cores at <10υm resolution. Trace elements analyses were performed with the UMaine Thermo Electron Element2 ICP-MS. The use of an ESI Apex high-sensitivity inlet system increased instrument sensitivity and reduced oxide formation in the plasma, lowering detection limits and allowing less abundant isotopes to be measured. A Cetac (Omaha, NE) Model ASX- 260 autosampler is located within our class-100 HEPA clean bench adjacent to the instrument to further reduce contamination. The ICP MS is calibrated daily with five standards that bracket the expected sample concentration range. Certified water reference material, SLRS-4 (Environment Canada) was used to verify the calibration. Similar to the method used by Krachler et al., (2005) checked standards are analyzed throughout the run to monitor long term drift. We used Thermo Electron?s auto lock mass software routine to compensate for mass drift. In an effort to minimize sample handling and possible contamination no internal standard was used.

Findings: (See PDF version submitted by PI at the end of the report)

Research accomplishments to date:

IPICS 2ka theme: Once the SPRESSO core is completely analyzed we will have the highest resolution 2ka yr ice core available from Antarctica. Without a doubt there will be more additional 2ka cores resulting from IPICS activities and it is our intention that the SPRESSO core will provide a benchmark for resolution and quality.

Eemian-Holocene comparison: The Mt. Moulton Eemian record is complete (isotopes, ions, trace elements) and will be submitted by Elena Korotkikh for publication by June. The Mt. Moulton Eemian record will be compared with the SPRESSOR results since they are of comparable resolution in order to compare late stage interglacial environments.

Sea ice proxy: Our previous work demonstrates the robust reconstructions available from ice cores for past temperature, atmospheric circulation, precipitation, chemistry of the atmosphere, sea ice extent, biomass burning, volcanic activity, and marine productivity. As an example, highly statistically significant correlations have been developed by us and by our colleagues between ice core records and instrumented climate records where, for example: Na+ ice core concentrations provide a proxy for the Amundsen Sea Low pressure system, ice core methanesulphonic acid and non sea salt sulfate concentrations a proxy for El N?no event frequency and sea ice extent, and ice core non-sea-salt calcium concentrations a proxy for SHW intensity. Our sea ice extent proxy research was among the earliest in the field (Welch et al., 1993; Meyerson et al., 2002). The Meyerson et al. (2002) research provided a 500-year long sea ice extent proxy based on methylsulfonate measurements from a South Pole ice core. A large impetus for the analysis of the SPRESSO core is to extend the sea ice extent proxy back to 2ka. However, since our early work we have and others have investigated the use of not just methylsulfonate but also sodium and non seasalt sulfate as sea ice etxent proxies. Our current activities in this regard utilize satellite-derived maximum, mean, and minimum sea ice extent in 36-10? sectors around Antarctica. The satellite record was used in the Meyerson et al (2002) work but we now have more than one additional decade for comparison. The preceding satellite derived data are correlated to mean and maximum sodium, non-sea salt sulfate, and methylsulfonate concentrations from several cores including SPRESSO. Correlations greater than the 90% confidence interval are examined on a regional basis (East Antarctica, Ross Sea, Amundsen-Bellingshausen Seas, Antarctic Peninsula, and Weddell Sea). We find that while there are numerous statistically robust associations no single chemical species is a proxy for sea ice extent from all regions nor in all cores. For South Pole the methylsulfonate ? sea ice extent association is still robust, but so also is the association with non seasalt sulfate. A complete synthesis of these associations for a multiple core array should be available for submission to a journal by S. Sneed et al., in the next few months.

Training and Development:

Year 1:
Elena Korotkikh (PhD student supported by this project) developed the Mt. Moulton Eemian record for her MSc (near complete) and is transitioning her skills to work on the South Pole ice core. This transition has necessitated going from sampling large volume Mt. Moulton trench samples to South Pole 4' diameter core samples. Further, the South Pole core research includes a new measurement parameter the 'Klotz' particle counter. Interfacing the CCI CMS sampling system with the Klotz counter has provided significant training in instrumentation and significant development.

Year 2:
Elena Korotkikh (PhD student supported by this project)has processed a total of 13,240 co-registered samples collected each for IC (ion chromatography), ICP MS (inductively coupled plasma sector field mass spectrometry) and MS (mass spectrometer stable water isotope analysis). She is also integrally involved with each of the analytical tools noted above and will conduct the multi-parameter annual layer counting based on ~8-9 samples/year.

Sharon Sneed (PhD student not supported by this grant, but conducting the IC measurements for this project) will use results from the SPRESO record to assess the role of MS, sodium, and non seasalt sulfate as proxies for sea ice extent.

Year 3: E. Korotkikh is expected to complete her PhD by June 2011. Her PhD research has been supported by the SPRESSO project. Because of the extremely large number of samples (18,570) and the 28 co-registered analyses per sample it has not been possible to fully complete this project. It is expected that all analyses needed for the project will be complete by December 2010 and several peer reviewed papers will be submitted for her PhD by June 2011. E. Korotkikh's SPRESSO and Mt. Moulton research represent an immense contribution to our understanding of Eemian and late Holocene climate change. She has produced the highest resolution, multi-parameter full Eemian and late Holocene climate records ever produced.

Outreach Activities:

Year 1:
The Climate Change Institute takes advantage of numerous opportunities for outreach that include information from this project and others being transmitted through a variety of venues including: public media (TV, magazine, newspaper), public talks, and development of a CCI graduate student white paper on climate change that will be one of the focal points for a forthcoming State-Wide climate change meeting at the University of Maine (23-24 October) entitled: CC^21 - Climate Change in the 21st Century.

Year 2:
The Climate Change Institute hosted CC^21 - 'Climate Change and the 21st Century' with >500 attendees, produced a general document for the public that presents basic concepts related to global environmental change, and produced 'Maine's Climate Future' at the request of Maine's Governor John Baldacci.

CCI researchers involved in this project gave numerous public lectures and media appearances including most recently NOVA.

Year 3:
E. Korotkikh has given several presentations of her SPRESSO results to school students visiting CCI and included her data in our emerging cyberinfrastructure activity. P. Mayewski gave 15 public presentations this year and several media interviews.

Journal Publications

J.T. Turner, R. Bindschadler, P. Convey, G. di Prisco, E. Fahrbach, D. Hodgson P.A. Mayewski, C. Summerhayes, "ACCE (Antarctic Climate Change and the Environment)", Scientific Committee for Antarctic Research, p. , vol. ISBN 97, (2009). Published, http://www.scar.org/publications/occasionals/acce.html

Hodgson DA, Abram N, Anderson J, Bargelloni L, Barrett P, Bentley MJ, Bertler NAN, Chown S, Clarke A, Convey P, Crame A, Crosta X, Curran M, di Prisco G, Francis, J.E., Goodwin I, Gutt J, Mass?? G, Masson-Delmotte V, Mayewski PA, Mulvaney R, Peck L, P??rt, "Antarctic climate and environmental history in the pre-instrumental period. In: Turner J, Convey P, di Prisco G, Mayewski PA, Hodgson DA, Fahrbach E, Bindschadler R (eds) Antarctic Climate Change and the Environment", Scientific Committee for Antarctic Research, p. , vol. ISBN 97, (2009). Published, http://www.scar.org/publications/occasionals/acce.html.

Hodgson DA, Abram N, Anderson J, Bargelloni L, Barrett P, Bentley MJ, Bertler NAN, Chown S, Clarke A, Convey P, Crame A, Crosta X, Curran M, di Prisco G, Francis, J.E., Goodwin I, Gutt J, Mass?? G, Masson-Delmotte V, Mayewski PA, Mulvaney R, Peck L, P??rt, "Antarctic climate and environmental history in the pre-instrumental period. In: Turner J, Convey P, di Prisco G, Mayewski PA, Hodgson DA, Fahrbach E, Bindschadler R (eds) Antarctic Climate Change and the Environment", Scientific Committee for Antarctic Research, p. , vol. ISBN 97, (2009). Published, http://www.scar.org/publications/occasionals/acce.html

John Turner, Jonathan Shanklin, Mike Sparrow, Rob Arthern, Andrew Fleming, David Bromwich, Gareth Marshall, Tony Worby, James Bockheim, Guido di Prisco, Cinzia Verde, Pete Convey, Zhaomin Wang, Howard Roscoe, Anna Jones, David Vaughan, Philip Woodworth, T, "Observations, data accuracy and tools, In: editors J.T. Turner, R. Bindschadler, P. Convey, G. di Prisco, E. Fahrbach, D. Hodgson P.A. Mayewski, C. Summerhayes", Scientific Committee for Antarctic Research, p. , vol. ISBN978, (2009). Published, http://www.scar.org/publications/occasionals/acce.html

Convey, P. Turner, J., DiPrisco, G., Mayewski, P.A., Hodgson, D.A., Fahrbach, E., Bindschadler, R., Gutt, J. and Summerhayes, C., "Antarctic climate change and the environment", Antarctic Science, p. , vol. , (2010). Accepted,

Mahowald, N., Kloster, S., Engelstaedter, S., Moore, J.K., Mukhopadhyay, S., McConnell, J., A;bani, S., Doney, S., Bhattacharya, A., Curran, M., Flanner, M., Hoffman, Lawrence, F., Lindsay, K., Mayewski, P.A., Neff, J., Rothenberg, D., Thomas, E., Thornt, "Observed 20th century desert dust changes: implications for climate and biogeochemistry", Atmospheric Chemistry and Physics, p. , vol. , (2010). Submitted,

Dixon, D. A., Mayewski, P.A., Goodwin, I., Freeman, R., Maasch, K.A., Sneed, S.B., and G. Marshall, "An ice core proxy for northerly air mass incursions (NAMI) into West Antarctica", International Climate Science, p. , vol. , (2010). Submitted,

Sneed, S.B., Mayewski, P.A., and Dixon, D., "Multi-ice core sodium, nss-sulfate, and methlysulfonate correlations with Antarctic sea ice extent - an enhanced ice core sea ice extent proxy", Annals of Glaciology, p. , vol. , (2010). Published,

Korotkikh, E., Mayewski, P. A., Handley, M., Introne, D., Sneed, S., Kurbatov, A., Dunbar, N. and McIntosh, W., "The last interglacial in West Antarctica", Quaternary Science Reviews, p. , vol. , (2010). Submitted,

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Product Type:

Software (or netware)

Product Description:

P301dx is a workbench for managing scientific datasets related to climate-change research, with an emphasis on data from ice cores produced by CCI researrchers (S. Chawathe, A. Kurbatov, P. Mayewski and M. Royer and several CCI graduate students (E. Korotkikh, N. Spaulding, S. Sneed, B. Grogholm, D. Dixon, M. Potocki). The primary objective of P301dx is enhancing and accelerating the process of transforming raw datasets, such as those emerging from instruments, into meaningful representations that allow data to be easily interpreted. This process of transforming the data includes sub-tasks such as data cleaning, data integration, data mining, end-user programming, visualization, and provenance management. P301dx enables these tasks to be performed iteratively and with interactive response times, in a context that is tailored to the specific needs of climate-change researchers. We demonstrate these ideas using a few representative examples drawn from our recent and ongoing work with a group of CCI researchers (faculty, staff, and students).

Sharing Information:

P301dx is still in preparation although early stages have been extensively tested. Once complete our goal is to make *P301dx* available to the public.

Contributions

Contributions within Discipline:

This project will help to raise the bar in ice core research by expanding the versatility of contamination-free, replicable core processing to include not just sampling for stable isotopes, soluble ons and trace elements, but also particles.

In addition CCI UM is training a graduate student at UI inice core processing to allow heir lab to expand its analytical capability.

The CCI core processing techniques has also been exported to scientists in India, New Zealand, Australia, and Canada.

CCI provided two major new cyberinfrastructure innovations:
(1) The IceREADER website maintained by CCI for SCAR has been completely remodeled so that it now receives and delivers individual password protected data facilitating rapid data renewal and sharing.
(2) p301 is an experimental tool for data access, manipulation, plotting and sharing.

Contributions to Other Disciplines:

CCI provided two major new cyberinfrastructure innovations:
(1) The IceREADER website maintained by CCI for SCAR has been completely remodeled so that it now receives and delivers individual password protected data facilitating rapid data renewal and sharing.
(2) p301 is an experimental tool for data access, manipulation, plotting and sharing.

Contributions to Human Resource Development:

Through this project CCI is training graduate students to integrate and interface new technologies and scientific interpretations.

Contributions to Resources for Research and Education:

CCI provided two major new cyberinfrastructure innovations:
(1) The IceREADER website maintained by CCI for SCAR has been completely remodeled so that it now receives and delivers individual password protected data facilitating rapid data renewal and sharing.
(2) p301 is an experimental tool for data access, manipulation, plotting and sharing.

Contributions Beyond Science and Engineering:

The SPRESSO ice core record will be the highest resolution, multi-parameter record of late Holocene Antarctic climate change available to date. It provides a baseline for assessing current and future change in: temperature, net mass balance, atmospheric circulation, soluble ions, and trace elements.

Conference Proceedings

Categories for which nothing is reported:

Any Book

Any Web/Internet Site

Any Conference

Recent Major Findings:

Summary as of May 2010

Research completed.

Three primary products have appeared thus far related to the SPRESSO (South Pole) ice core record.

(1) E. Korotkikh (graduate student supported by the SPRESSO grant) completed the most detailed record of Eemian climate thus far produced. This record provides an essential comparison with the emerging SPRESSO Holocene climate record allowing comparison of the latter stages of the current and last interglacial.

(2) SPRESSO core data was used to define the characteristics of westerly (zonal) flow around the continent.

(3) SPRESSO core data was used to develop the first multi-ice core, multi-parameter test for a sea ice extent proxy.

Details of the three products noted above follow:

(1) The Mount Moulton Eemian ice trench record high resolution (~6-8 years per sample) and contains a suite of 28 co-registeres measurements (3795 samples), including major anions, trace elements and water hydrogen isotopes. Comparison with other Antarctic ice core records covering the Eemian demonstrates that the site preserves the full duration of the Eemian (Fig. 1). The Mt. Moulton Eemian record demonstrates that different environmental proxies do not necessarily respond simultaneously to changes in climate making it essential to combine several to define the characteristics and duration of the last interglacial. A combined examination of Mt. Moulton ice trench seasalts, $nssSO_4^{2-}$ and δD (Fig. 2) and dust (Fig. 3) indicates that the end of the last interglacial in West Antarctica was gradual and occurred sometime between 113 – 123.8 ka B.P. Whether the last interglacial lasted ~10,500 or ~21,000 years, the end of this interglacial does not hint at any of the dramatic changes related to warming in climate that are either on-going or projected for Antarctica in the future further verifying the non-natural causes for the modern changes. Comparison of the SPRESSO late Holocene and Mt. Moulton Eemian records will provide the first multi-parameter (28 properties), high resolution, co-registered comparison of interglacial climates.

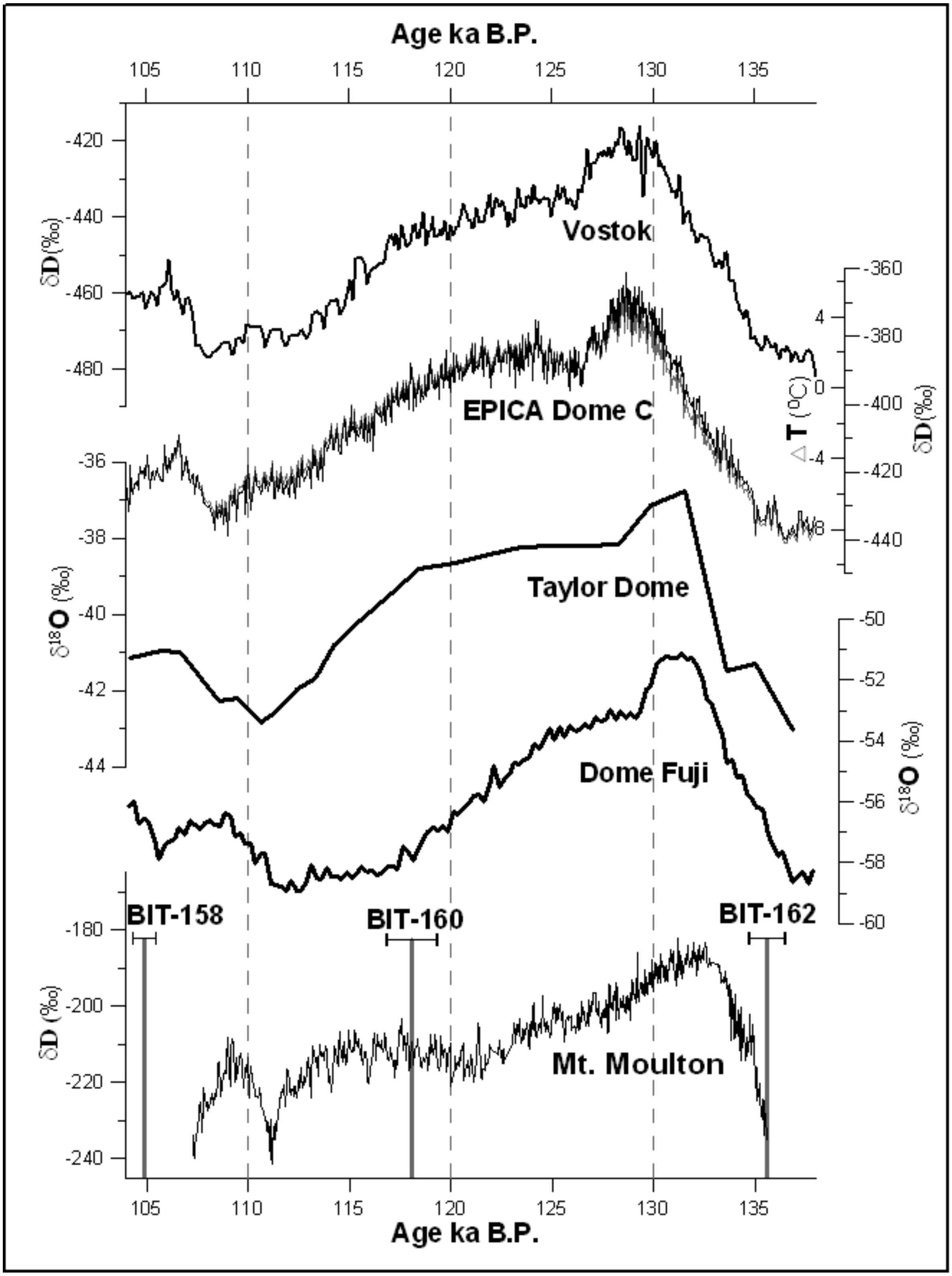


Figure 1. Comparison of stable isotope records from Antarctica covering the last

interglacial and transition to the next glacial period. Stable isotope profiles at Mt. Moulton (this study), Dome Fuji (Kawamura et al., 2007), Taylor Dome (Steig et al., 2000; Grootes et al., 2001), EPICA Dome C (Jouzel et al., 2007) and Vostok (Petit et al., 1999) for the period from 104 to 140 ka B.P. Also added EPICA Dome C temperature anomaly (temperature difference from the average of the last 1000 years) (Jouzel et al., 2007). Positions of the three tephra layers (BIT-158, 160, 162) in the Mt. Moulton BIA are also shown.

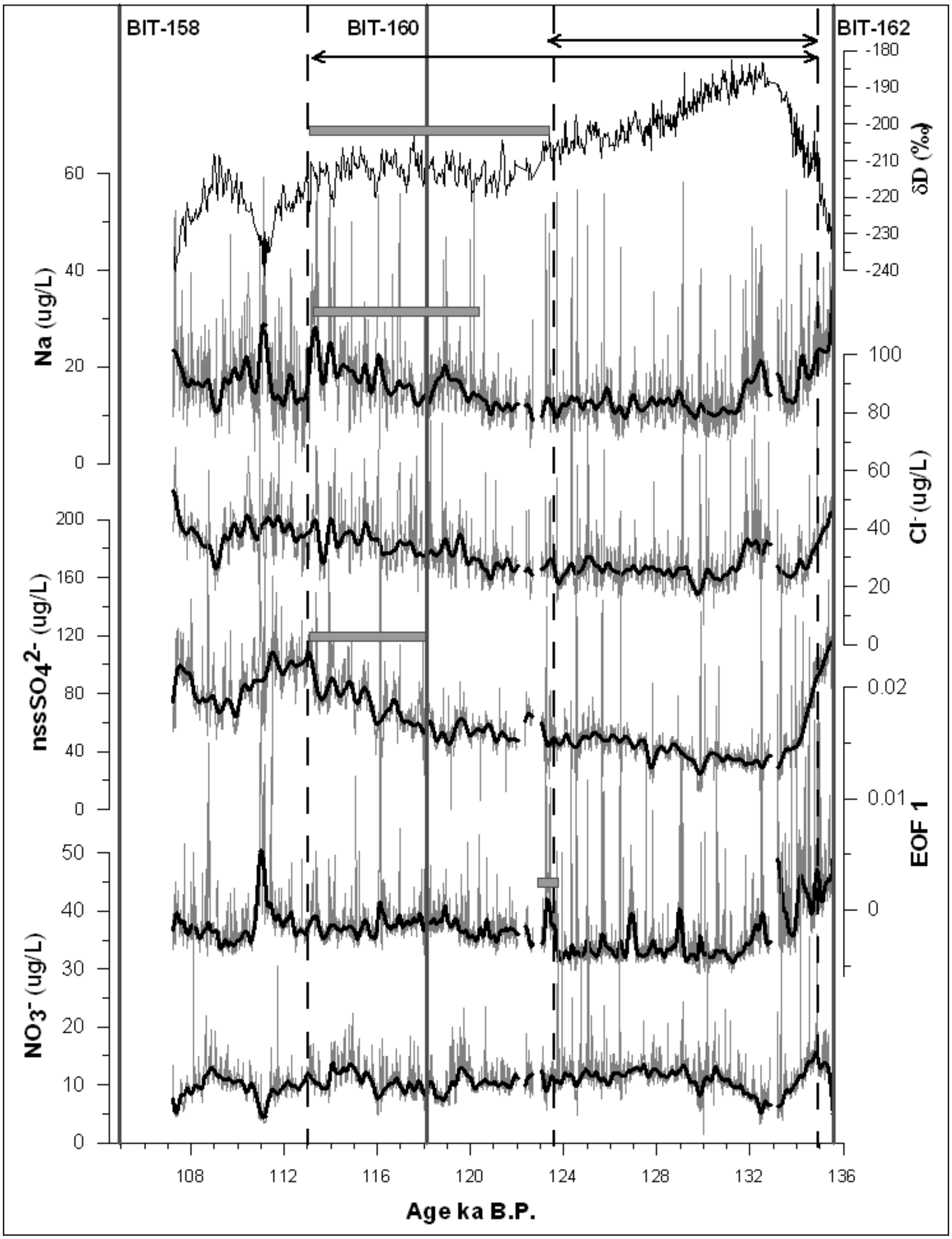


Figure 2. Mt. Moulton glaciochemical record for the period from 107 to 136 ka B.P. Mt. Moulton time series (from top to bottom): δD (‰), Na (ug/L), Cl^- (ug/L), $nssSO_4^{2-}$ (ug/L), NO_3^- (ug/L), EOF1. The light color lines are raw data and the dark color lines are

the mean background level (estimated using a robust spline). Positions of the three tephra layers (BIT-158, 160, 162) used to date the record are also shown. Arrows represent possible durations of the last interglacial. Grey rectangles represent the range of timing for the end of the last interglacial inferred from different time series.

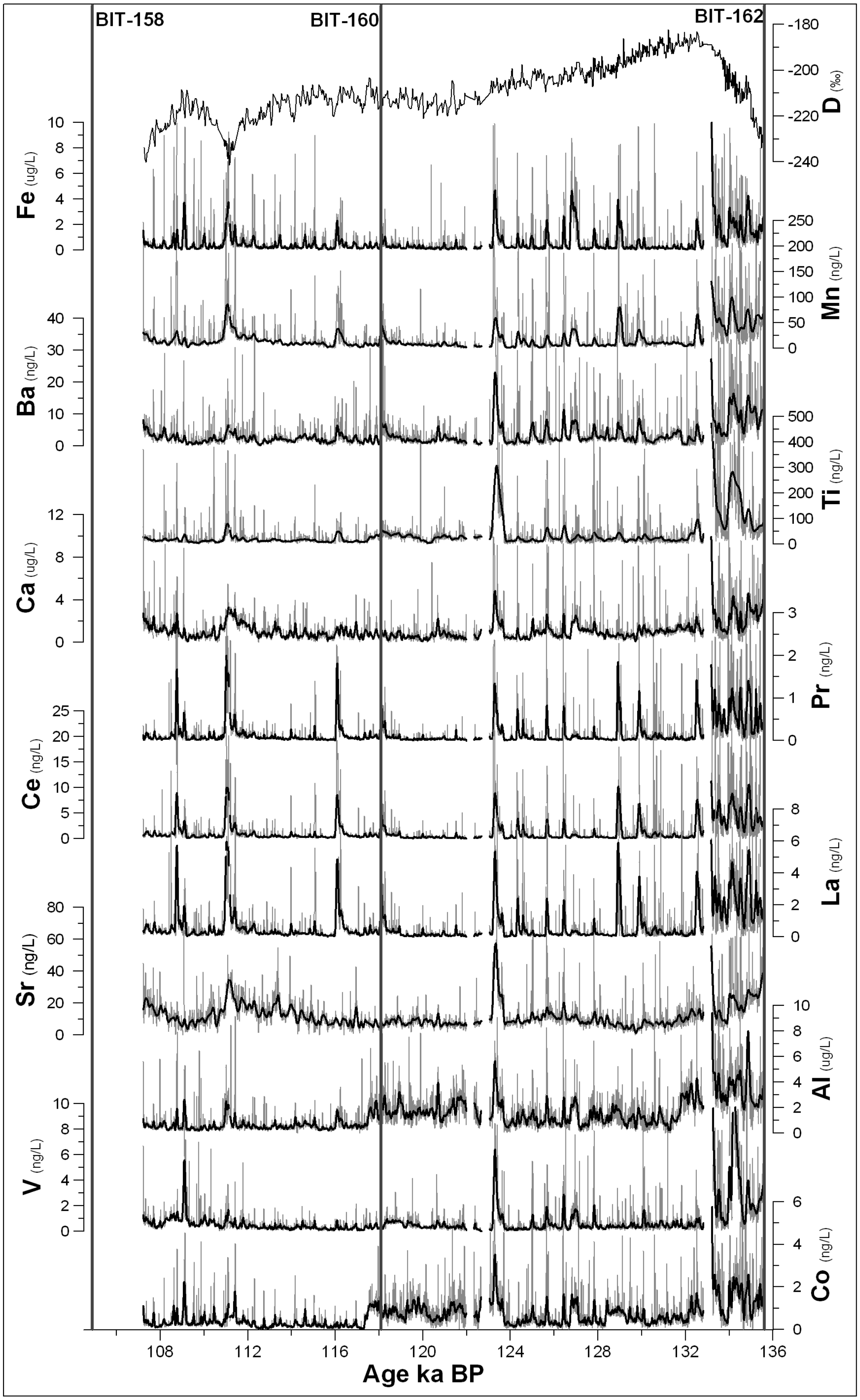

BIT-158
BIT-160
BIT-162
D (‰)
Fe (ug/L)
Mn (ng/L)
Ba (ng/L)
Ti (ng/L)
Ca (ug/L)
Pr (ng/L)
Ce (ng/L)
La (ng/L)
Sr (ng/L)
Al (ug/L)
V (ng/L)
Co (ng/L)
Age ka BP

Figure 3. Mt. Moulton dust record for the period from 107 to 136 ka B.P. Elements highly loaded in EOF1 (from top to bottom): Fe (ug/L), Mn (ng/L), Ba (ng/L), Ti (ng/L), Ca (ug/L), Pr (ng/L), Ce (ng/L), La (ng/L), Sr (ng/L), Al (ug/L), V (ng/L) and Co (ng/L). The light color lines are raw data and the dark color lines are the mean background level (estimated using a robust spline). The positions of three tephra layers (BIT-158, BIT-160 and BIT-162) are also shown.

(2) Despite Antarctica's remote location the impact of human activity is becoming increasingly evident. Greenhouse gas induced warming and ozone depletion are both changing the dynamics of high-latitude Southern Hemisphere climate, notably the strength of the Southern Hemisphere circumpolar westerly wind (SHW). Correlation between NCEP reanalysis data and nssCa in US ITASE ice cores demonstrates that nssCa is positively correlated with changes in the 850 mb pressure field surrounding Antarctica. Examination of the spatial distribution of nssCa for US ITASE ice core records covering East and West Antarctica reveals change in the intensity of the westerly wind field as early as the mid-19th century with greatest intensification in recent decades (fig. 1).

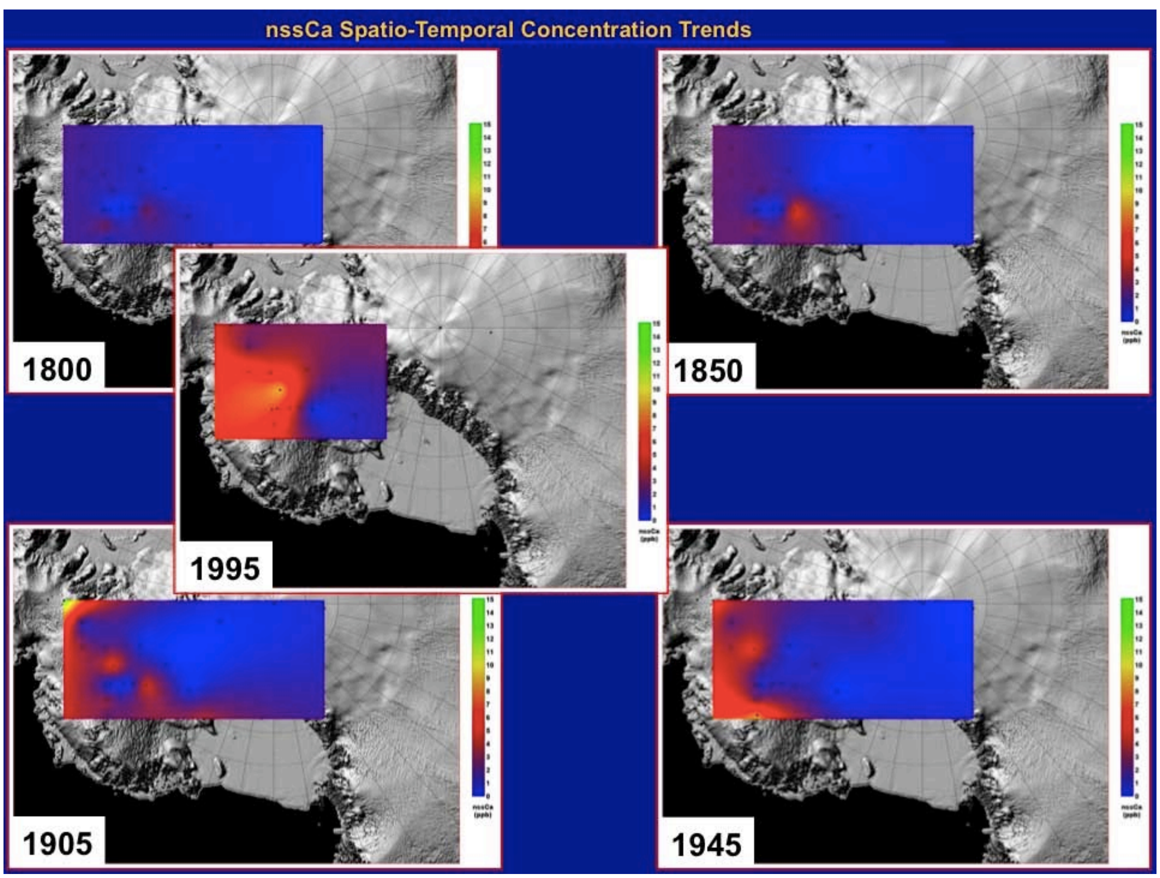
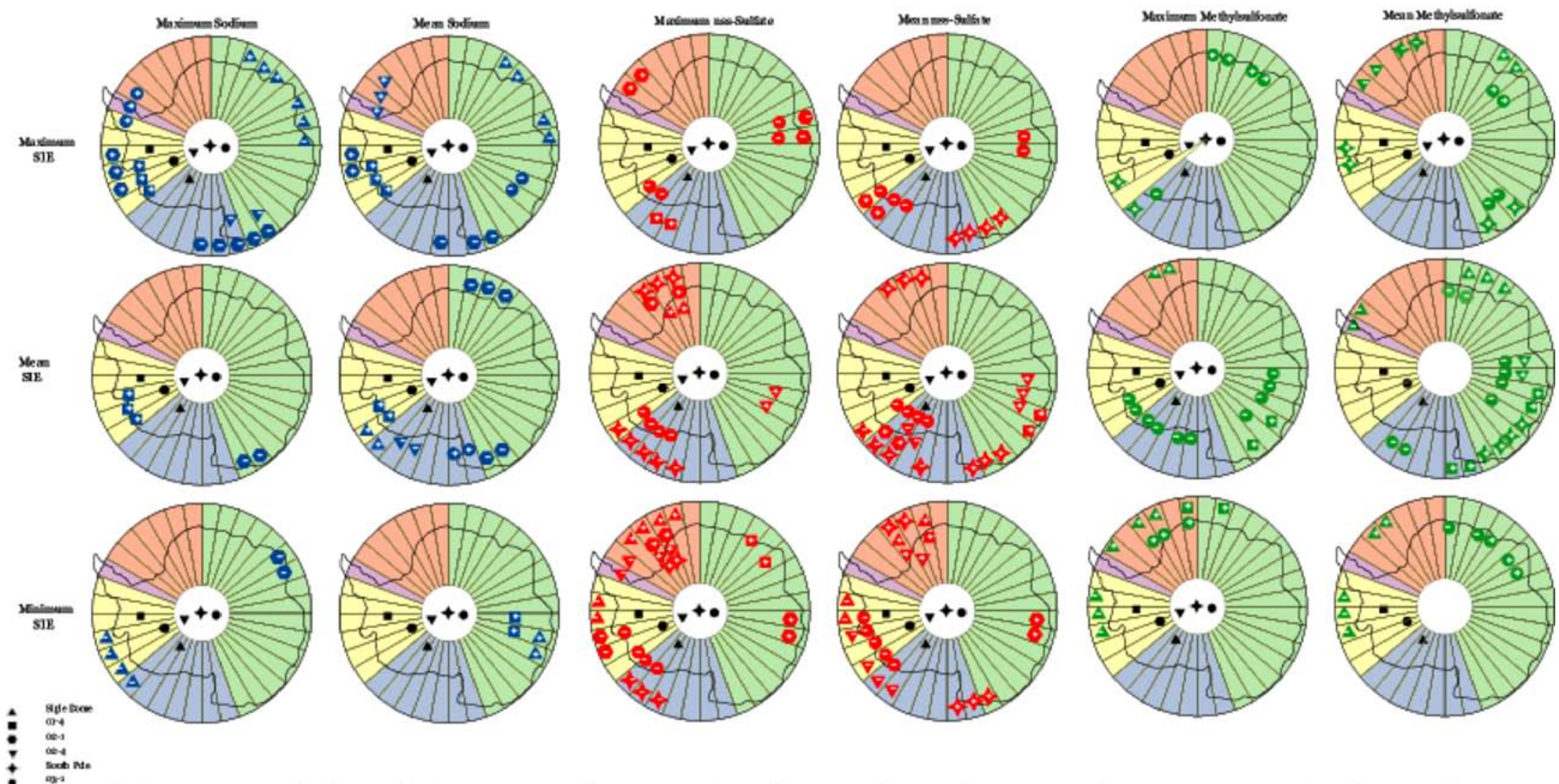


Figure 1 – Snapshots in time of change in nssCa (ppb) summarized from an array of annually resolved ice cores (black dots) including the SPRESSO ice core. Blue (no change) and red (increase).

Since the source of nssCa is dust, primarily from extra-Antarctic regions such as South America and Australia), and nssCa is a proxy for westerly flow (as noted by our previous work reported in Yan et al., 2006) the increase in nssCa represents intensification of westerly flow surrounding Antarctica and possibly migration of the region of westerly flow southward (contraction of the polar vortex). Our interpretation (Dixon et. al., in review) supports the finding that the westerlies are speeding up and moving closer to Antarctica as suggested by D. Thompson and S. Solomon (2002) consistent with changes in the thermal gradient induced by lower stratospheric ozone depletion. Our findings demonstrate, however, that the westerly flow regime change started earlier than would have due solely to CFC impacted ozone depletion and is therefore also consistent with changes in circulation reported by Mayewski et al. (2005) related to change in solar variability and the initial phases of greenhouse gas rise. Our finding that nssCa (westerly proxy) levels increase most markedly in recent decades suggests that the most recent and intense change in the westerlies is consistent with the importance of the impact of ozone depletion. The nssCa example presented here demonstrates that both natural and anthropogenically forced change in climate must be considered in examining current change over Antarctica. In addition our SHW proxy shows that intensification since ~1980 is unprecedented for at least the last 5400 years by extrapolation into the Siple Dome deep ice core record. Also demonstrated is the potential for SH atmospheric circulation to shift abruptly from an enhanced state as exists today to a relatively weak state. Such weakening of the SHW could hasten Antarctic warming and have significant impacts on future SH climate and sea level. Modelling activities to be conducted in the near future will address this potential.

(3) The seasonal to decadal scale and longer growth and retreat of Antarctic sea ice imparts significant changes in deep ocean water formation and ventilation, albedo and subsequent feedback loops, and both primary production and phytoplankton blooms. Variability in sea ice is assessed by determining extent from the continent, duration, areal extent, and amount of adjacent open water. In all cases measurements are significantly more accurate and extensive since the implementation of satellite observations. Antarctic ice cores provide a valuable proxy record of past climate. The primary proxies used for sea ice reconstruction are sodium, non-sea salt sulfate, and methanesulfonic acid. These are routinely measured using ion chromatography at the ppb level. Sodium is representative of sea salt inputs and is preserved and measured in ice cores as Na^+. Sources of non-sea salt sulfate ($nssSO_4^{2-}$) include atmospheric inputs (natural and anthropogenic), biogenic contributions, and volcanic emissions. Breakdown of phytoplankton cells and subsequent oxidation reactions is the only source of methanesulfonic acid in Antarctica and it is preserved and measured in ice cores as methylsulfonate (MS^-). To better understand these associations we examined the maximum and mean concentrations of Na^+, $nssSO_4^{2-}$, and MS^- in US ITASE ice cores

including the SPRESSO ice core and correlated them to the maximum, mean, and minimum sea ice extents for 36-10˚ sectors around Antarctica. Correlations (fig. 2 below) are highly promising. While previous sea ice extent ice core proxies (including our own) have primarily focused on the use of a single chemical species our new approach demonstrates that multiple proxies afford complimentary but expanded interpretations. These interpretations may allow finer differentiation of sea ice extent seasonal timing and geographic location.



Linear correlations between sea ice extent and annual maximum and mean concentrations of sodium (blue), nss-sulfate (red), and methylsulfonate (green) for 6 Antarctic cores: Siple Dome(▲), 01-4 (■), 02-1 (⬢), 02-4 (▼), South Pole (✦), and 03-1 (●). Correlations were calculated for each of the 36-10° sectors around Antarctica. All plotted values are greater than the 90% confidence interval and for all but 10 02-4 correlations at least one correlation is at the 95% confidence interval. Highlighted regions are: East Antarctica (0° to 160°, green), Ross Sea (160° to 230°, blue), Amundsen-Bellingshausen Seas (230° to 290°, yellow), Antarctic Peninsula (290° to 300°, lilac), and the Weddell Sea (300° to 360°, red).

Research papers in preparation for E. Korotkikh PhD thesis.

(1) Develop an ~2000 year long, annually dated, sub-annually resolved reconstruction of past climate (including temperature, atmospheric circulation, precipitation, sea ice extent and marine productivity) to investigate annual to centennial climate variability. In previous work by Meyerson et al (2002) the ice core recovered from South Pole was analyzed for the marine biogenic sulfur species methanesulfonate (MS) revealing an ~500 year long proxy record of the polar expression of the El Niño- Southern Oscillation (ENSO) and southeastern Pacific sea-ice extent variations. The SPRESSO to sea ice extent correlation has been verified based on newer ice core and sea ice extent data (see sea ice paper in review above) allowing a sea ice extent proxy of ~2000 years ago from the SPRESSO core once all analyses are complete (Fig. 1).

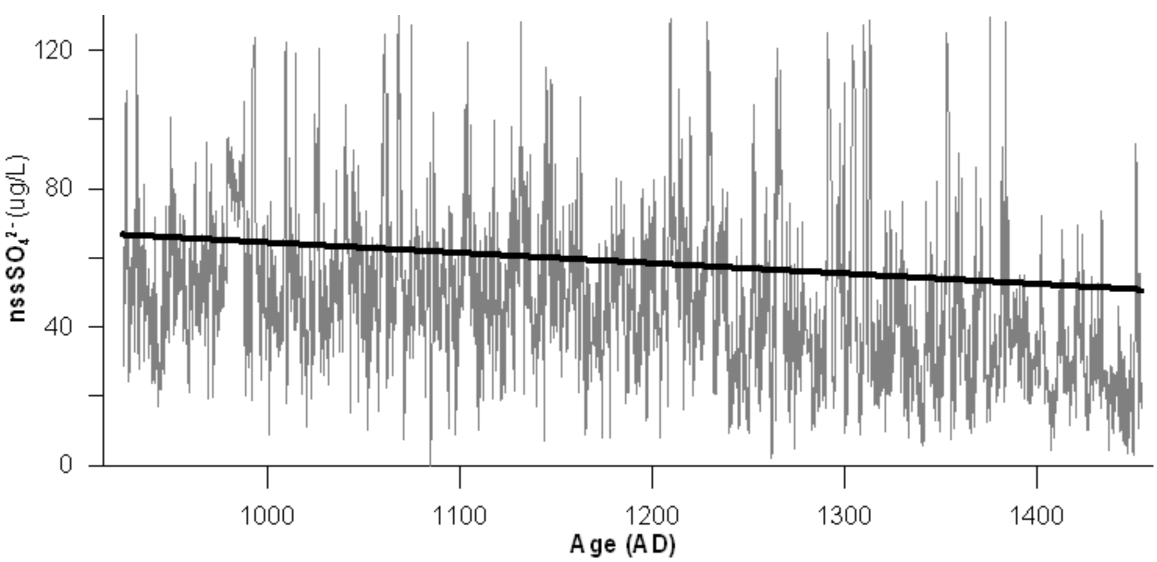


Figure 1 - Non-sea-salt sulfate ($nssSO_4^{2-}$) concentration for the period AD 945 – 1455 years. Black line is a linear regression. $nssSO_4^{2-}$ shows a decrease in concentration since AD945.

(2) Develop an ~2000 year long, sub-annually resolved record of trace elements to investigate changes in transport and sources of trace elements to East Antarctica. Compare natural and anthropogenic sources. As an example Ba demonstrates a dramatic recent rise (Fig. 1). Ba is the 14th most abundant element in the Earth's crust. Barium enters the atmosphere through mining processes, refining processes, production of barium compounds, and through coal combustion.

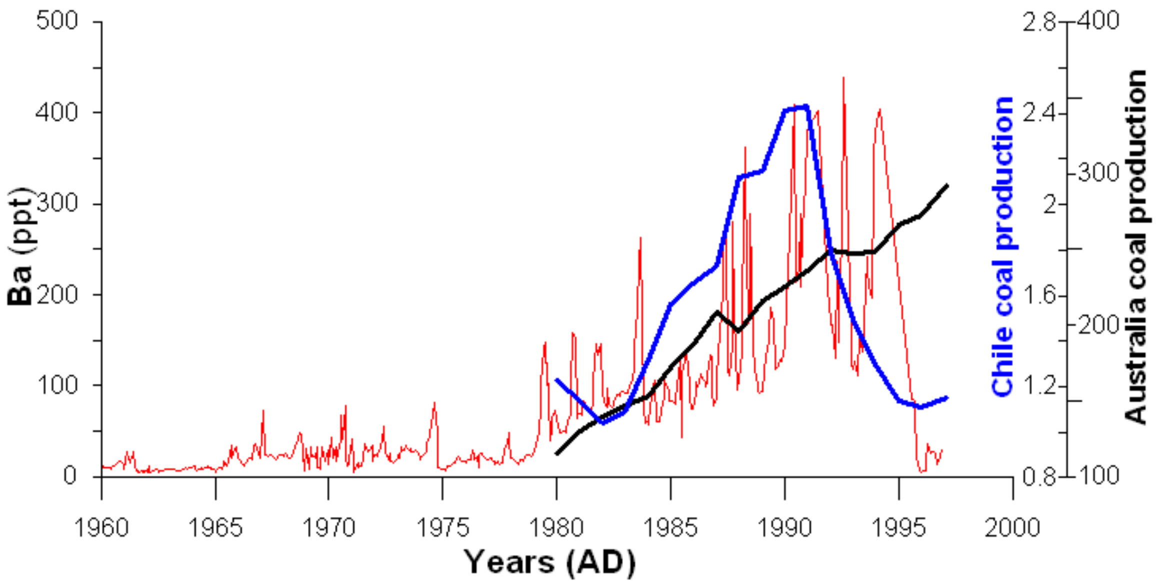


Figure 2 – Ba rise in the SPRESSO record compared to coal production in Chile and Australia.

As shown on the plot above Ba concentrations start to rise around 1980. The enrichment factor (EF) for Ba also rises since 1980 (from 1 to 20-40) demonstrating that the Ba rise is not from natural sources. In 1984 Australia became the world's largest coal exporter. Ba has a similar pattern to Australian coal production, except for the period ~1997-1996. During this time Ba shows a big drop in concentration, but Australian coal production still rises. In contrast Chilean coal production declined since 1991. We will continue to investigate this and the other trace element records.

(3) Develop an ~2000 year long South Pole volcanic record to investigate the influence of volcanic activity on climate. Examples of notable eruptions appear in Fig. 3.

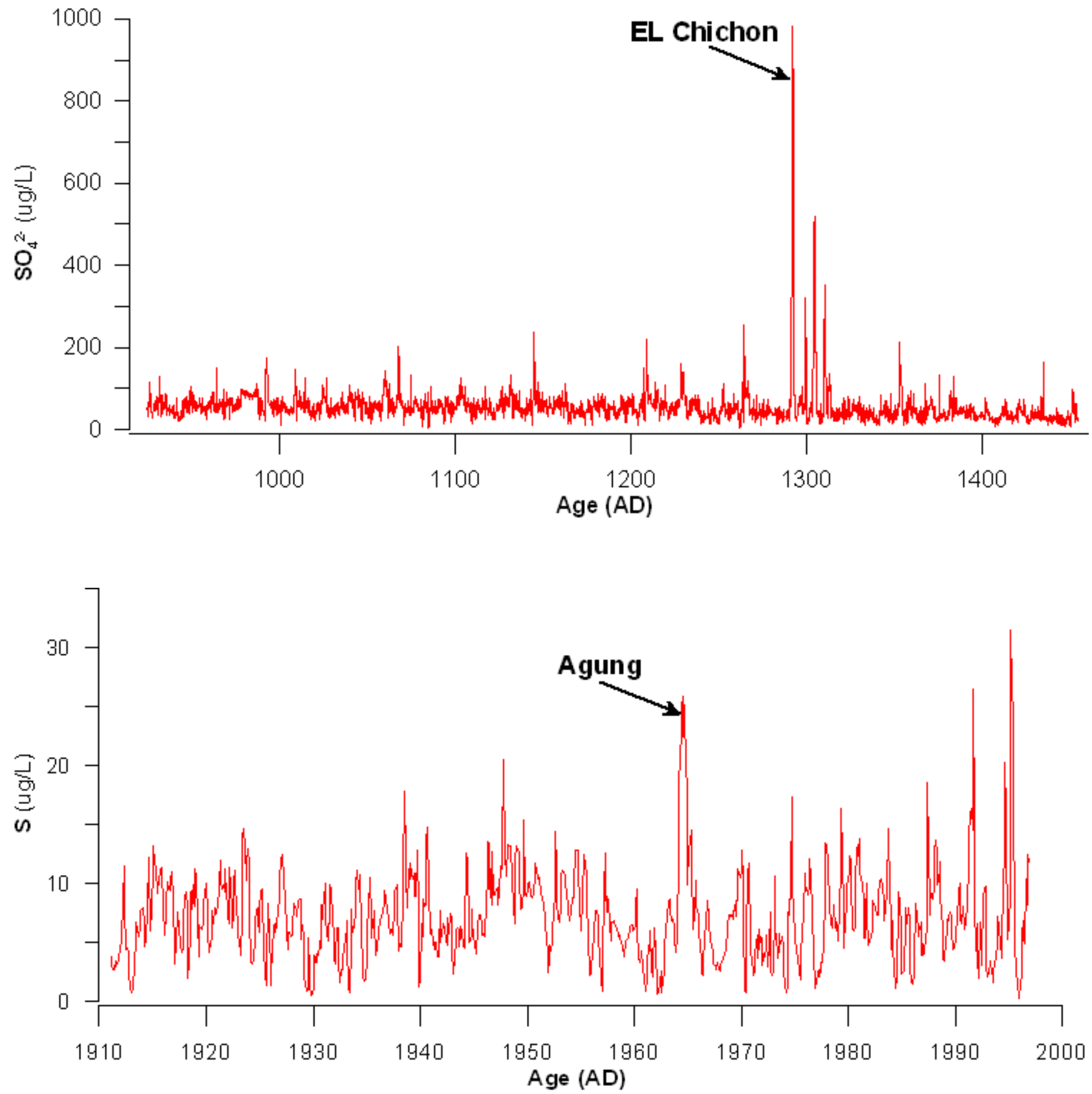


Figure 3 – Examples of well preserved volcanic signals in both soluble $SO_4^{=}$ (IC) and total S (ICP MS).

(4) Develop ~2000 year long, sub-annually resolved record of dust aerosol loading to investigate dust impact on climate.

(5) Compare SPRESSO glaciochemical data with 200+ year long ITASE ice core data and 2000 year long ice core data from Taylor, Siple and Low Dome, GISP2, Mt. Everest and Mt. Logan plus other paleoclimate records (marine sediment, coral, calcite, pollen) to investigate regional to global scale spatial and temporal climate variability.