4-28-2002

Siple Dome Deep Ice Core Glaciochemistry and Regional Survey - A Contribution to the WAIS Initiative

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Final Report for Period: 07/2000 - 04/2002
Submitted on: 04/28/2002
Principal Investigator: Mayewski, Paul A.
Award ID: 0096305
Organization: University of Maine
Title:
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Project Participants

Senior Personnel

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

Name: Meeker, Loren
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Kreutz, Karl
Worked for more than 160 Hours: Yes
Contribution to Project:
Participated in field, laboratory and interpretation.

Name: Meyerson, Eric
Worked for more than 160 Hours: Yes
Contribution to Project:
Particpated in laboratory analysis and interpretation.

Undergraduate Student

Name: Bridges, Kelly
Worked for more than 160 Hours: Yes
Contribution to Project:
Laboratory assistant.

Name: Darrow, Erin
Worked for more than 160 Hours: Yes
Contribution to Project:
Laboratory assistant.

Name: Stanisewski, Erin
Worked for more than 160 Hours: Yes
Contribution to Project:
Laboratory assistant.

Name: Story, Sarah
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Lynch, Colleen

Worked for more than 160 Hours: No
Contribution to Project:

Name: Dawson, Andrew
Worked for more than 160 Hours: No
Contribution to Project:

Name: Smith, Jeremy
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Sirois, Alexander
Worked for more than 160 Hours: Yes
Contribution to Project:

Other Participant

Name: Duan, Hui
Worked for more than 160 Hours: No
Contribution to Project:

Name: Lorrey, Andrew
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Friedman, Daryl
Worked for more than 160 Hours: No
Contribution to Project:

Research Experience for Undergraduates

Organizational Partners

University of Nevada Desert Research Institute

University of Colorado at Boulder

Princeton University

CRREL

University of Washington

Penn State University

Other Collaborators or Contacts

All of the other Siple Dome investigator institutions.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

ACTIVITIES AND FINDINGS
Activities

Research and Education Activities:

Our project focuses on the analysis and interpretation of major ions and methanesulfonate (in conjunction with the Univ. of Miami) from a deep ice core at Siple Dome, Antarctica. In addition, this study investigates the regional glaciochemical variability on Siple Dome, continuing work begun during the 1994 field season. The first field season for this project was conducted during the 1996/97 austral season. Because this project closely follows work begun in 1994, selected glaciochemical results from 1994 are presented, along with reports that detail Siple Dome research to present.

a. Siple Dome Glaciochemistry (1994)
-Glaciochemical data from snowpits and ice cores collected during the 1994 field season contain strong annual signals in all chemical species. In particular, sulfate, nitrate, sodium, chloride, and methanesulfonate have easily identifiable, large amplitude summer/winter concentration changes. Summer peaks in sulfate and nitrate correspond to well defined depth hoar layers in the snowpack.

-Analysis of beta radioactivity in 1994 Siple Dome samples indicates a peak 7.87-8.84m, corresponding to the 1964 nuclear testing horizon. Accumulation rate estimates based on these findings are 14.6-15.58 cm ice/yr. There appears to be a gradient in accumulation rate on Siple Dome, with higher accumulation rates on the north side of the ice divide.
-A continuous melter system was developed for analysis of Siple Dome ice cores. This system currently allows continuous measurements of chloride, nitrate, and liquid conductivity. Results from the 1994 core indicate that continuous melter analyses provide accurate dating using annual chemical signals at all core depths. We are utilizing this system in dating all cores collected for this project.
-A depth/age scale for the 1994 core has been developed using beta horizons, annual chemical signals (from both discrete and continuous melter sampling), stratigraphy, and volcanic horizons (e.g., Krakatoa and 1259 AD eruptions). The estimated age at 150m depth is 838 AD.

b. 1996 Field Work
During the first field season of this project (1996/97), we were involved in a successful ice core collection program with the assistance of the Polar Ice Coring Office (PICO). Site selection for the Siple Dome deep ice core was performed by drilling a 100m shallow core at the main core site. The 100m core was collected according to UNH protocol to ensure minimal contamination. Core quality down to 100m was very good to excellent. Field observations of core stratigraphy suggest that annual layering is present throughout the 100m core. Two additional shallow cores (15m each) were drilled at the site for high-resolution density measurements. A density profile for the entire 100m core is attached. The firn/ice transition in both the 1994 and 1996 cores is estimated to be ~53. An estimated depth/age scale (based on results from the 1994 core) is also

attached. Depth/age scales for 1996 cores will be developed using identical techniques, and are expected to be similar to the 1994 core depth/age scale.
-Snowpit collection included sampling of a 4m pit at the main drill site, and 2m pits at 10km and 30km on either side of the Siple Dome ice divide. Shallow (~100m) cores are scheduled to be drilled at each of the remote sites, which will provide a more complete view of glaciochemical spatial variability on Siple Dome.
-Glaciochemical analysis of 1996 samples will commence in Spring, 1997 when the snowpit samples reach UNH. Sampling of the 100m core will be performed at NICL in early summer, 1997. Completion of analysis for all 1996 samples is scheduled for late summer, 1997.

c. Results from the 1997/98 Field Season
During the 1997/98 field season at Siple Dome, the University of New Hampshire (UNH, Glaciochemistry) did not send personnel to the field because we have already conducted extensive spatial sampling in the region and because of logistical constraints. UNH did participate in the successful core processing line at NICL in June 1998 and attended the West Antarctic Ice Sheet (WAIS) Cores meeting in Orono, Maine in September, 1998. Glaciochemical analysis is complete for the detailed sampling and continuous flow sampling of the hot water core, as well as detailed sampling of the upper 30m of the Upstream C core. Sampling of the Siple Dome A Core is underway and samples are being provided for the University of Miami (methanesulfonate) and the University of California at Berkley (cosmogenic isotopes). UNH also provided a member to the Siple Dome Dating Committee. Following is a progress report on the 1997/98 Siple Dome ice cores along with some preliminary results.
-The hot water core sections collected by B. Kamb and H. Engelhardt were processed at the 1998 summer NICL multi-instiutional core processing line. Sections shipped back to UNH consisted of ~2m long ice cores from every ~100m starting at a depth of ~100m down to 978m. High resolution (~2cm) sampling on ~1m core sections from each 100m depth was conducted and the samples were analyzed for the major ions. A continuous flow system was used to analyze for liquid conductivity, chloride, and nitrate for ~2m core sections from each 100m depth. The sodium and sulfate depth series from the detailed analysis demostrate that annual signals are apparent to a depth of ~500m. The full suite of ion chemistry will be merged with ECM, DEP, stratigraphy, and continuous flow chemistry for annual layer counting. The full suite of chemistry averaged over the detailed sections shows that the average values for sodium and sulfate are within the range of values demonstrated by the 1994 glaciochemical series (Kreutz et al., 1997). The downward trend in both species starting at ~100m appears to be continued in the hot water core to at least ~200m.
-The analysis of the major ions of the Siple Dome A Core is complete to a depth of 55m and the analysis of remaining core collected during the 1997/98 field season is currently underway, with an estimated completion date of January-Feburary 1999. Continuous flow analysis for liquid conductivity, chloride, and nitrate is complete to a depth of 60m.
-High resolution analysis of the upper 15m of the Siple Dome B Core is complete. Continuous flow analysis for liquid conductivity, chloride, and nitrate is complete to 100m.
-Figure 1 (From Annual Report in 1999). High resolution (~2cm sampling interval) sodium (Na) and sulfate (SO4) depth series in parts

per billion (ppb) for (A) ~100m to ~500m and for (B) ~600 to ~1000m.
-Figure 2 (From Annual Report in 1999). Average chemical concentrations for ~1m core sections from ~100m to ~1000m of the high resolution (~2cm) analysis for the major ions (Na, K, Mg, Ca, NH4, Cl, NO3, SO4) in parts per billion (ppb).
-Figure 3 (From Annual Report in 1999). A comparison of Na and SO4 from 30m to 300m from the 1994 core (Kreutz et al., 1997) and the average chemical concentrations from the hot water core high resolution (~2cm) analysis.

d. Major Research Findings (1998-99 to 2001):
Preliminary results from the A-Core were presented at the September 1999 WAISCORES meeting in Virgina. At that time, available glaciochemical data down to 196m, dated to ~1800 years before 2000 A.D. (yb2k) with a preliminary depth/age scale (R. Alley, pers. comm., 1999), was presented. Figure 1 (previous annual report, accompanying jpeg file) shows the A-Core sodium (Na+) time series compared to the 94-Recon-Core sodium
(Kreutz et al., 1997). This is a remarkable similarity between the overlapping portions of these two records. The Little Ice Age (LIA) variability, discussed in Kreutz et al. (1997), is also seen in the A-Core. The A-Core sodium also displays the gradual increase before the LIA that is seen in the 94-Core. The A-Core shows that sodium levels are slightly higher at ~1800 yb2k than they are just prior to the LIA.

e. Mid- to Late-Holocene Climate History
The Siple Dome A-Core deep drilling project in West Antarctica provides a detailed look into long-term climate variations. High resolution (approx. bi-annual sampling) ion chromatography analysis was conducted on this core to produce glaciochemical time series of the major cations (Na, Mg, Ca, K) and anions (Cl, SO4, NO3). Previous work has linked variations in the Siple Dome glaciochemistry to atmospheric pressure changes in the Amundsen-Ross Seas region of the southern Pacific Ocean. This instrumental calibration allows the Siple Dome ion chemistry to be used to investigate past atmospheric circulation changes in this region of the Southern Pacific.
The background sea-salt trend in the Siple Dome is generally increasing from the mid-Holocene (approx. 5000 years before present) to the present. The corresponding trend in insolation at 60 degrees Latitude for this time period is decreasing for the season of sea-salt deposition September-October). This relationship is inverse to the background sea-salt values over the same period in the Greenland Ice Sheet Project Two (GISP2) (O'Brien et al., 1995). GISP2 displays decreasing sea-salt values over the same time period that correspond to an increasing trend in insolation at 60 degrees North in the winter (December-February), the season of sea-salt deposition at GISP2. The relationship between the orbital cycles and atmospheric circulation variations represented by the ice core sea-salts appear to have influence on long-term time scales as well as in conjunction with other climate events.
These background trends in sea-salts also have an influence on the transition into the classic Little Ice Age (LIA) climate change event seen at Siple Dome and GISP2. Kreutz et al. (1997) discussed the presence of elevated sea-salts during the LIA at Siple Dome and compared this to the elevated sea-salts seen in the GISP2 record (O'Brien et al., 1995). The recent extension of the Siple Dome time scale shows that increase in sea-salts at Siple Dome precede the increase in sea-salts in GISP2.
In addition to constructing a longer bipolar comparison between Siple Dome and Greenland, the Siple Dome record helps complete a transect of chemistry sites across the Pacific sector of Antarctica. The quality of these ice cores records (Siple Dome, Taylor Dome, South Pole, Law Dome) allows for detailed survey of the last 1000 years. Variations in these records show climate events within the LIA that have similar timings and structure as seen in the tree ring Carbon-14 residuals (proxy for solar irradiance). There are, however, differences in these cores that most likely arise from the different atmosphere circulation patterns across the Pacific sector of Antarctica.

f. Holocene and Glacial Climate History

The ~98ky glaciochemical record recovered from Siple Dome reveals strong source signals from the ocean (seasalt (ssNa, ssK, ssMg, ssCa, ssCl, ss-sulfate) and biogenic non-ss-sulfate), volcanism (excess-sulfate), remote continental dust (nssK, nssCa), and katabatic flow (nitrate, biogenic nss-sulfate). The strongly calibrated Siple Dome seasonal (Sept-Nov) signature in seasalt species is dominated by the strength (SLP) of the Amundsen Sea Low (ASL). This calibration has predicated a record of the Antarctic Oscillation (AAO): specifically the ASL (West Antarctica) and the East Antarctic High (EAH), East Antarctica. The well-preserved Siple Dome Holocene structure is similar to the GISP2 Holocene (Figure 1) suggesting a strong association between ASL behavior and that of GISP2 proxies for the Icelandic Low (Na) and the Siberian High (K). The pre-Holocene climate record from Siple Dome (Figure 2) is quite different from other Antarctic records because the glacial age ASL (the major source for marine air) is significantly north of its Holocene position as a consequence of changes in boundary conditions (e.g., size of EAH, sea ice extent, ice sheet configuration, grounding line retreat in Ross Sea at ~75OO years before present). The Little Ice Age expansion and deepening of the ASL is the most dramatic event in the full Siple Dome Holocene-Glacial atmospheric circulation record.

g. Data Synopsis

Ice core processing to date (April 2002):
(a) A-Coreùbi-yearly continuous, 0-600m; multi-year continuous 600-1004m; continuous flow analysis, 0-154m.

(b) 1994-Coreùcontinuous flow analysis, 0-150m; bi-yearly continuous, 60-150m; sub-annual continuous, 0-60m.

(c) B-Coreùcontinuous flow analysis, 0-100m; sub-annual continuous, 0-13m.

(d) Hot Water Coreùsub-annual continuous, ~2m sections for every ~100m for ~1000m.

Data Archive (April 2002):
All the data has been compiled and archived with the Siple Dome (WAISCores) Science Coordination Office (SCO) at http://waiscores.dri.edu/. After June 2002, this data will be archived at the Antarctic Glaciological Data Center (NSF OPP) at http://nsidc.org/agdc/index.html.

h. Siple Dome A-Core Sample and Sub-Sample Generation

The Siple Dome A-Core was transported from the field to the National Ice Core Laboratory (NICL) situated at the United States Geological Survey in Denver, Colorado. The major ion chemistry (Mayewski, PI) and tephra (Zielinski, PI) ice sections were partitioned as one entire section from the Siple Dome A-core together during the many summer Siple Dome core processing line sessions at NICL and transported back to freezer laboratory facilities at the University of New Hampshire and later, the University of Maine. The major ion chemistry section (3.5 cm by 3.5 cm area section for every meter) was processed with melter head systems that obtained the center of each sample. From this sample, aliquots for cations (Na+, K+, Mg2+, Ca2+) and anions (Cl-, SO42-, NO3-) were taken for analyses with ion chromotography. Sub-sample aliquots for methanesulfate (Saltzman, PI) for each sample were taken at this time and sent off. The remaining sample was then used for tephra analyses (Zielinski, PI). The melter head systems produced a sub-sample that was also collected for cosmogenic isotopes (Nishizumi, PI). In addition to this collection process, the cosmogenic isotope samples were treated with nitric acid and a beryllium tracer, and then prepared and shipped to the University of California at Berkeley.

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

ACTIVITIES AND FINDINGS
Findings:

Major findings include thus far:
1. Ice core proxy for Amundsen Sea Low and hindcasted record.
2. Identification of ENSO impact on West Antarctica.
3. Joint investigation of Siple Dome, Taylor Dome, and Law Dome Holocene records to identify associated features and forcings plus non-associated factors.
4. Chemical signature of pre-Holocene Antarctic rapid climate change events.
5. Holocene record of environmental change (eg., sea ice, volcanism, atmospheric circulation).
6. The major ion series have strong seasonal signals.
7. The major ion series provide histories of volcanic events, marine storminess, katabatic wind events that affect West Antarctica
8. Seasalt series are strongly correlated with SLP fluctuations in the region of the Amundsen Sea Low and surrounding ocean.
9. Siple Dome experienced a dramatic increase in marine storminess during the period classically termed the Little Ice Age (LIA; nominally recorded in the literature as occurring from 1350-1900 A.D.
10. The Siple Dome LIA-event has an onset time that is coincident with that of the LIA in the North Atlantic based on a correlation with the GISP2 record.

11. The Siple Dome LIA-like event is the most dramatic (i.e., highest sustained chemical concentrations) climate seen in the Siple Dome Holocene-Glacial (~98ky BP) glaciochemical record
12. The SD Holocene record contains evidence of many of the Holocene rapid climate change events seen in the GISP2 Holocene record and a gobal assemblage of other Holocene records
13. The Siple Dome Holocene trend in ion series is related to insolation during the deposition of seasalt (September-November).
14. The Siple Dome Holocene ion record offers important insights into global climate change when viewed in the context of a global array of Holocene climatic records.
15. The pre-Holocene ion record has both close parallels with the Taylor Dome pre-Holocene record and notable dissimilarities. The dissimilarities indicate that the Siple Dome region was not dominated by the Amundsen Sea Low influences during the pre-Holocene as a consequence of significant expansion of sea ice, local ice surface topography, regional ice surface topography, or continental scale differences in atmospheric circulation.
16. Interpretation of the Siple Dome major ion record has been greatly facilitated by US ITASE ice core interpretations.

Training and Development
Training and Development:

a) Several students were/are involved in this project including:
Dr. Karl J. Kreutz (Ph.D. completed June 1998) was involved in the field and laboratory program, spatial analysis studies, and time-series analysis from ice cores. Ph.D. dissertation based data generated from this grant.

Eric A. Meyerson (Ph.D. Student) is involved with processing and laboratory program related to the Siple Dome A-Core and his dissertation will be based on data generated from this grant.

Several M.Sc. students (Eric A. Meyerson, David B. Reusch) and undergraduate work study students (Joseph M. Souney, Kelly A. Bridges, Erin Darrow, Erin Stanisewski, Sarah A Story, Colleen Lynch, Hui Duan, Andrew Dawson, Jeremy B. Smith, Alexander Sirois) were involved in sample processing
and laboratory analysis. Additional personnel were also involved in the sample processing:
Andrew Lorrey, Daryl Friedman, Sam Kelley (High School Student; Orono, Maine), Chris Zielinski (High School Student; Bangor, Maine).

b) Data collected as part of this program was and will be used as an integral part of a senior/graduate level course in paleoclimate analysis.

Outreach
Outreach Activities:

a) Public and peer awareness of the program is being promoted by participating in several interviews with newspaper reporters plus public lectures (average 10/year to grammar schools, high schools, and adults) plus invited presentations at scientific conferences.
b) Representation nationally and internationally via presentations and meetings (over past year) by Lead PI P.A. Mayewski at:
Great Bay Rotary Club
Harvard Travellers Club
Boston Bay Group
Osgood Lecture, Wooster College, Ohio
US ITASE High School Teachers Workshop
Public lectures û Boston Museum of Science
IMAGES Meeting, Trins, Austria
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Journal Publications

Mayewski, P.A., Meeker, L.D., Twickler, M.S., Whitlow, S.I., Yang, Q., Kreutz, K.J., and Reusch, D., "Major changes in atmospheric circulation deduced from a Greenland Ice Core and comparison with an Antarctic ice core", Cryosphere, p. , vol. , ( ). Accepted

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Reusch, D.B., P.A. Mayewski, S.I. Whitlow, and M.S. Twickler, "Spatial variability and past atmopheric circulation patterns from central West Antarctic glaciochemistry", Journal of Geophysical Research, p. 5985, vol. 104, (1999). Published

Mayewski, P.A., and E. Barron, "Paleoclimate Overview, Chapter 6, Global Environmental Change: Research Pathways for the Next Decade, National Academy of Sciences Global Change Report", National Academy of Sciences, p. , vol. , (   ). Accepted

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, "Antarctic multi-decadal scale climate variability
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Books or Other One-time Publications

Mayewski, P.A., and F. White, "The Ice Chronicles: The quest to understand global climate change", (02). Book, Published
Bibliography: University of New Hampshire and the University Press of New England, Hanover, New Hampshire, 2002

Web/Internet Site

URL(s):

www.maxey.dri.edu/WRC/waiscores/index.html
Description:
Science Coordination Office for Siple Dome Project containing description of project and updates.

Other Specific Products

Contributions

Contributions within Discipline:

1. Ice core proxy for Amundsen Sea Low and hindcasted record.
2. Identification of ENSO impact on West Antarctica.
3. Joint investigation of Siple Dome, Taylor Dome, and Law Dome Holocene records to identify associated features and forcings plus non-associated factors.
4. Chemical signature of pre-Holocene Antarctic rapid climate change events.
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9. Siple Dome experienced a dramatic increase in marine storminess during the period classically termed the Little Ice Age (LIA; nominally recorded in the literature as occurring from 1350-1900 A.D.
10. The Siple Dome LIA-event has an onset time that is coincident with that of the LIA in the North Atlantic based on a correlation with the GISP2 record.
11. The Siple Dome LIA-like event is the most dramatic (i.e., highest sustained chemical concentrations) climate seen in the Siple Dome

Holocene-Glacial (~98ky BP) glaciochemical record
12. The SD Holocene record contains evidence of many of the Holocene rapid climate change events seen in the GISP2 Holocene record and a gobal assemblage of other Holocene records
13. The Siple Dome Holocene trend in ion series is related to insolation during the deposition of seasalt (September-November).
14. The Siple Dome Holocene ion record offers important insights into global climate change when viewed in the context of a global array of Holocene climatic records.
15. The pre-Holocene ion record has both close parallels with the Taylor Dome pre-Holocene record and notable dissimilarities. The dissimilarities indicate that the Siple Dome region was not dominated by the Amundsen Sea Low influences during the pre-Holocene as a consequence of significant expansion of sea ice, local ice surface topography, regional ice surface topography, or continental scale differences in atmospheric circulation.
16. Interpretation of the Siple Dome major ion record has been greatly facilitated by US ITASE ice core interpretations.

Contributions to Human Resource Development:

1. The findings from the Siple Dome A-Core major ion chemistry series have been presented to high school students and their teachers during science tours at a) the Climate Change Research Center, Univ. of New Hampshire and b) the Institute for Quaternary and Climate Studies, Univ. of Maine.
2. High school students have been involved in the freezer processing of the Siple Dome A-Core: a) Sam Kelley (Orono, Maine); and b) Chris Zielinski (Bangor, Maine).
3. The Siple Dome A-Core data has been extensively used in upper-level undergraduate/graduate level classes to illustrated the use of ice cores in understanding global climate change.

Contributions to Resources for Research and Education:

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3. The Siple Dome A-Core data has been extensively used in upper-level undergraduate/graduate level classes to illustrated the use of ice cores in understanding global climate change.

Contributions Beyond Science and Engineering:

Data and experience used extensively in public lectures.

Categories for which nothing is reported:

Any Product

ACTIVITIES AND FINDINGS

Activities

Research and Education Activities:

Our project focuses on the analysis and interpretation of major ions and methanesulfonate (in conjunction with the Univ. of Miami) from a deep ice core at Siple Dome, Antarctica. In addition, this study investigates the regional glaciochemical variability on Siple Dome, continuing work begun during the 1994 field season. The first field season for this project was conducted during the 1996/97 austral season. Because this project closely follows work begun in 1994, selected glaciochemical results from 1994 are presented, along with reports that detail Siple Dome research to present.

a. Siple Dome Glaciochemistry (1994)

-Glaciochemical data from snowpits and ice cores collected during the 1994 field season contain strong annual signals in all chemical species. In particular, sulfate, nitrate, sodium, chloride, and methanesulfonate have easily identifiable, large amplitude summer/winter concentration changes. Summer peaks in sulfate and nitrate correspond to well defined depth hoar layers in the snowpack.

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During the first field season of this project (1996/97), we were involved in a successful ice core collection program with the assistance of the Polar Ice Coring Office (PICO). Site selection for the Siple Dome deep ice core was performed by drilling a 100m shallow core at the main core site. The 100m core was collected according to

UNH protocol to ensure minimal contamination. Core quality down to 100m was very good to excellent. Field observations of core stratigraphy suggest that annual layering is present throughout the 100m core. Two additional shallow cores (15m each) were drilled at the site for high-resolution density measurements. A density profile for the entire 100m core is attached. The firn/ice transition in both the 1994 and 1996 cores is estimated to be ~53. An estimated depth/age scale (based on results from the 1994 core) is also attached. Depth/age scales for 1996 cores will be developed using identical techniques, and are expected to be similar to the 1994 core depth/age scale.

-Snowpit collection included sampling of a 4m pit at the main drill site, and 2m pits at 10km and 30km on either side of the Siple Dome ice divide. Shallow (~100m) cores are scheduled to be drilled at each of the remote sites, which will provide a more complete view of glaciochemical spatial variability on Siple Dome.

-Glaciochemical analysis of 1996 samples will commence in Spring, 1997 when the snowpit samples reach UNH. Sampling of the 100m core will be performed at NICL in early summer, 1997. Completion of analysis for all 1996 samples is scheduled for late summer, 1997.

c. Results from the 1997/98 Field Season

During the 1997/98 field season at Siple Dome, the University of New Hampshire (UNH, Glaciochemistry) did not send personnel to the field because we have already conducted extensive spatial sampling in the region and because of logistical constraints. UNH did participate in the successful core processing line at NICL in June 1998 and attended the West Antarctic Ice Sheet (WAIS) Cores meeting in Orono, Maine in September, 1998. Glaciochemical analysis is complete for the detailed sampling and continuous flow sampling of the hot water core, as well as detailed sampling of the upper 30m of the Upstream C core. Sampling of the Siple Dome A Core is underway and samples are being provided for the University of Miami (methanesulfonate) and the University of California at Berkley (cosmogenic isotopes). UNH also provided a member to the Siple Dome Dating Committee. Following is a progress report on the 1997/98 Siple Dome ice cores along with some preliminary results.

-The hot water core sections collected by B. Kamb and H. Engelhardt were processed at the 1998 summer NICL multi-instiutional core processing line. Sections shipped back to UNH consisted of ~2m long ice cores from every ~100m starting at a depth of ~100m down to 978m. High resolution (~2cm) sampling on ~1m core sections from each 100m depth was conducted and the samples were analyzed for the major ions. A continuous flow system was used to analyze for liquid conductivity, chloride, and nitrate for ~2m core sections from each 100m depth. The sodium and sulfate depth series from the detailed analysis demostrate

that annual signals are apparent to a depth of ~500m. The full suite of ion chemistry will be merged with ECM, DEP, stratigraphy, and continuous flow chemistry for annual layer counting. The full suite of chemistry averaged over the detailed sections shows that the average values for sodium and sulfate are within the range of values demonstrated by the 1994 glaciochemical series (Kreutz et al., 1997). The downward trend in both species starting at ~100m appears to be continued in the hot water core to at least ~200m.
-The analysis of the major ions of the Siple Dome A Core is complete to a depth of 55m and the analysis of remaining core collected during the 1997/98 field season is currently underway, with an estimated completion date of January-Feburary 1999. Continuous flow analysis for liquid conductivity, chloride, and nitrate is complete to a depth of 60m.
-High resolution analysis of the upper 15m of the Siple Dome B Core is complete. Continuous flow analysis for liquid conductivity, chloride, and nitrate is complete to 100m.
-Figure 1 (From Annual Report in 1999). High resolution (~2cm sampling interval) sodium (Na) and sulfate (SO4) depth series in parts per billion (ppb) for (A) ~100m to ~500m and for (B) ~600 to ~1000m.
-Figure 2 (From Annual Report in 1999). Average chemical concentrations for ~1m core sections from ~100m to ~1000m of the high resolution (~2cm) analysis for the major ions (Na, K, Mg, Ca, NH4, Cl, NO3, SO4) in parts per billion (ppb).
-Figure 3 (From Annual Report in 1999). A comparison of Na and SO4 from 30m to 300m from the 1994 core (Kreutz et al., 1997) and the average chemical concentrations from the hot water core high resolution (~2cm) analysis.

d. Major Research Findings (1998-99 to 2001):
Preliminary results from the A-Core were presented at the September 1999 WAISCORES meeting in Virgina. At that time, available glaciochemical data down to 196m, dated to ~1800 years before 2000 A.D. (yb2k) with a preliminary depth/age scale (R. Alley, pers. comm., 1999), was presented. Figure 1 (previous annual report, accompanying jpeg file) shows the A-Core sodium (Na+) time series compared to the 94-Recon-Core sodium (Kreutz et al., 1997). This is a remarkable similarity between the overlapping portions of these two records. The Little Ice Age (LIA) variability, discussed in Kreutz et al. (1997), is also seen in the A-Core. The A-Core sodium also displays the gradual increase before the LIA that is seen in the 94-Core. The A-Core shows that sodium levels are slightly higher at ~1800 yb2k than they are just prior to the LIA.

e. Mid- to Late-Holocene Climate History

The Siple Dome A-Core deep drilling project in West Antarctica provides a detailed look into long-term climate variations. High resolution (approx. bi-annual sampling) ion chromatography analysis was conducted on this core to produce glaciochemical time series of the major cations (Na, Mg, Ca, K) and anions (Cl, SO4, NO3). Previous work has linked variations in the Siple Dome glaciochemistry to atmospheric pressure changes in the Amundsen-Ross Seas region of the southern Pacific Ocean. This instrumental calibration allows the Siple Dome ion chemistry to be used to investigate past atmospheric circulation changes in this region of the Southern Pacific.

The background sea-salt trend in the Siple Dome is generally increasing from the mid-Holocene (approx. 5000 years before present) to the present. The corresponding trend in insolation at 60 degrees Latitude for this time period is decreasing for the season of sea-salt deposition September-October). This relationship is inverse to the background sea-salt values over the same period in the Greenland Ice Sheet Project Two (GISP2) (O'Brien et al., 1995). GISP2 displays decreasing sea-salt values over the same time period that correspond to an increasing trend in insolation at 60 degrees North in the winter (December-February), the season of sea-salt deposition at GISP2. The relationship between the orbital cycles and atmospheric circulation variations represented by the ice core sea-salts appear to have influence on long-term time scales as well as in conjunction with other climate events.

These background trends in sea-salts also have an influence on the transition into the classic Little Ice Age (LIA) climate change event seen at Siple Dome and GISP2. Kreutz et al. (1997) discussed the presence of elevated sea-salts during the LIA at Siple Dome and compared this to the elevated sea-salts seen in the GISP2 record (O'Brien et al., 1995). The recent extension of the Siple Dome time scale shows that increase in sea-salts at Siple Dome precede the increase in sea-salts in GISP2.

In addition to constructing a longer bipolar comparison between Siple Dome and Greenland, the Siple Dome record helps complete a transect of chemistry sites across the Pacific sector of Antarctica. The quality of these ice cores records (Siple Dome, Taylor Dome, South Pole, Law Dome) allows for detailed survey of the last 1000 years. Variations in these records show climate events within the LIA that have similar timings and structure as seen in the tree ring Carbon-14 residuals (proxy for solar irradiance). There are, however, differences in these cores that most likely arise from the different atmosphere circulation patterns across the Pacific sector of Antarctica.

f. Holocene and Glacial Climate History

The ~98ky glaciochemical record recovered from Siple Dome reveals strong source signals from the ocean (seasalt (ssNa, ssK, ssMg, ssCa, ssCl, ss-sulfate) and biogenic non-ss-sulfate), volcanism (excess-sulfate), remote continental dust (nssK, nssCa), and katabatic flow (nitrate, biogenic nss-sulfate). The strongly calibrated Siple Dome seasonal (Sept-Nov) signature in seasalt species is dominated by the strength (SLP) of the Amundsen Sea Low (ASL). This calibration has predicated a record of the Antarctic Oscillation (AAO): specifically the ASL (West Antarctica) and the East Antarctic High (EAH), East Antarctica. The well-preserved Siple Dome Holocene structure is similar to the GISP2 Holocene (Figure 1) suggesting a strong association between ASL behavior and that of GISP2 proxies for the Icelandic Low (Na) and the Siberian High (K). The pre-

Holocene climate record from Siple Dome (Figure 2) is quite different from other Antarctic records because the glacial age ASL (the major source for marine air) is significantly north of its Holocene position as a consequence of changes in boundary conditions (e.g., size of EAH, sea ice extent, ice sheet configuration, grounding line retreat in Ross Sea at ~75OO years before present). The Little Ice Age expansion and deepening of the ASL is the most dramatic event in the full Siple Dome Holocene-Glacial atmospheric circulation record.

g. Data Synopsis

Ice core processing to date (April 2002):
(a) A-Core—bi-yearly continuous, 0-600m; multi-year continuous 600-1004m; continuous flow analysis, 0-154m.

(b) 1994-Core—continuous flow analysis, 0-150m; bi-yearly continuous, 60-150m; sub-annual continuous, 0-60m.

(c) B-Core—continuous flow analysis, 0-100m; sub-annual continuous, 0-13m.

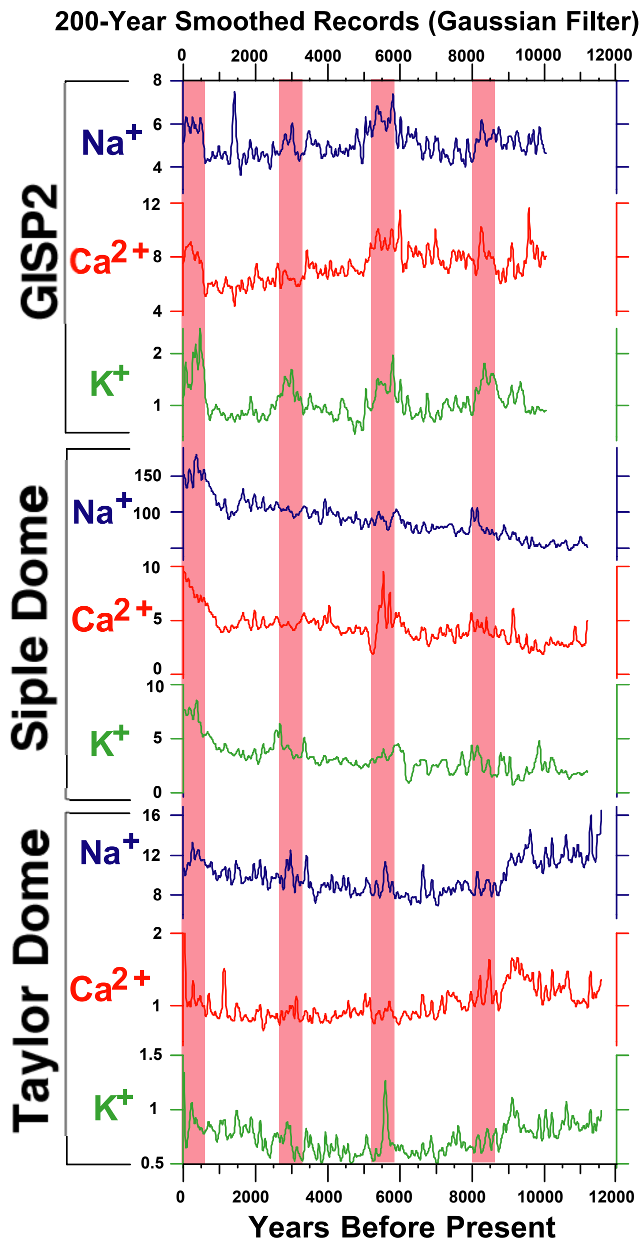
(d) Hot Water Core—sub-annual continuous, ~2m sections for every ~100m for ~1000m.

Data Archive (April 2002):
All the data has been compiled and archived with the Siple Dome (WAISCores) Science Coordination Office (SCO) at http://waiscores.dri.edu/. After June 2002, this data will be archived at the Antarctic Glaciological Data Center (NSF OPP) at http://nsidc.org/agdc/index.html.

h. Siple Dome A-Core Sample and Sub-Sample Generation

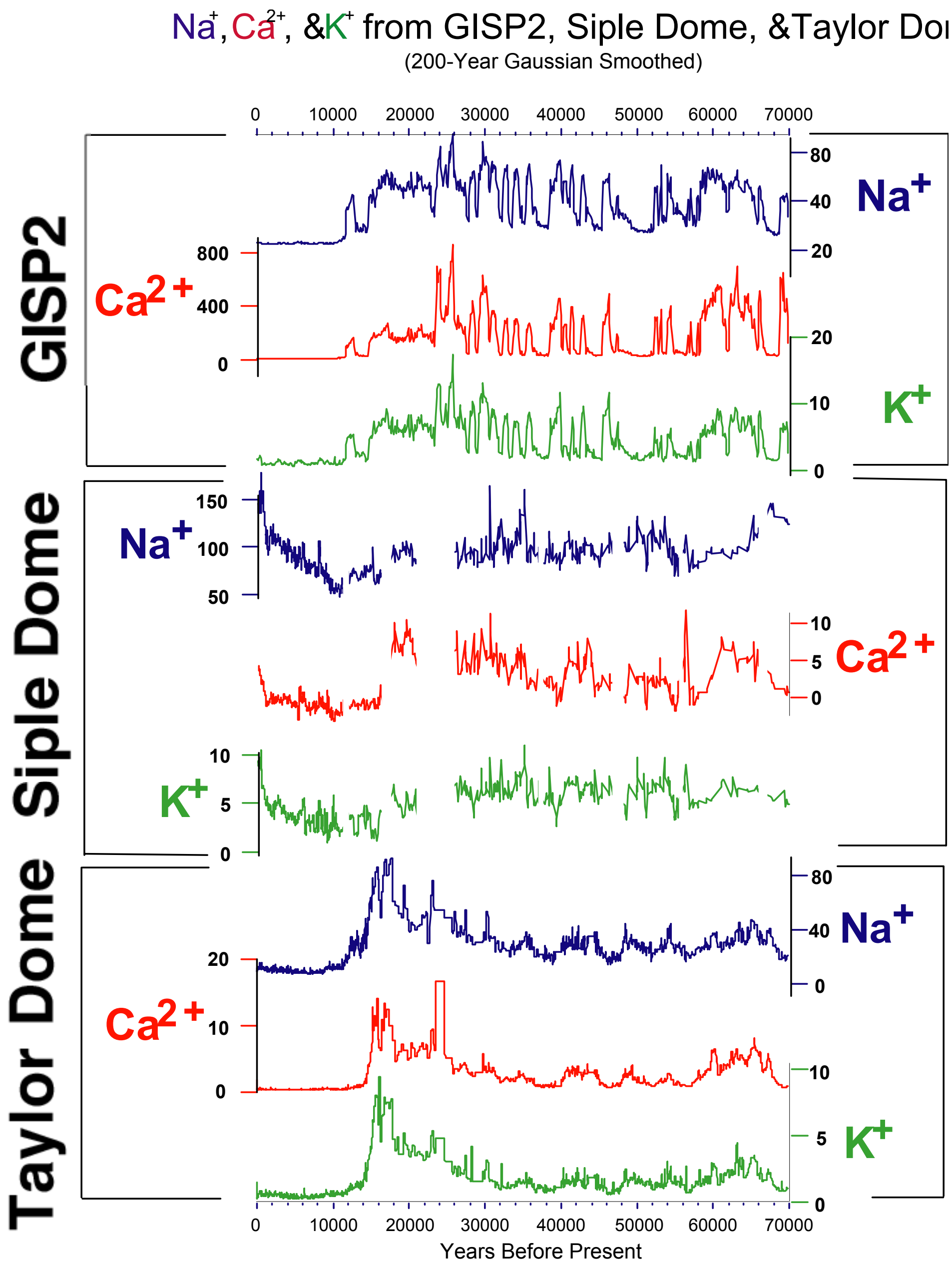
The Siple Dome A-Core was transported from the field to the National Ice Core Laboratory (NICL) situated at the United States Geological Survey in Denver, Colorado. The major ion chemistry (Mayewski, PI) and tephra (Zielinski, PI) ice sections were partitioned as one entire section from the Siple Dome A-core together during the many summer Siple Dome core processing line sessions at NICL and transported back to freezer laboratory facilities at the University of New Hampshire and later, the University of Maine. The major ion chemistry section (3.5 cm by 3.5 cm area section for every meter) was processed with melter head systems that obtained the center of each sample. From this sample, aliquots for cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anions (Cl^-, SO_4^{2-}, NO_3^-) were taken for analyses with ion chromotography. Sub-sample aliquots for methanesulfate (Saltzman, PI) for each sample were taken at this time and sent off. The remaining sample was then used for tephra analyses (Zielinski, PI). The melter head systems produced a sub-sample that was also collected for cosmogenic isotopes (Nishizumi, PI). In addition to this collection process, the cosmogenic isotope samples were treated with nitric acid and a beryllium tracer, and then prepared and shipped to the University of California at Berkeley.

Figure 1.



200-Year Smoothed Records (Gaussian Filter)
GISP2
Siple Dome
Taylor Dome
Na+
Ca2+
K+
0
2000
4000
6000
8000
10000
12000
Years Before Present

Figure 2.


Na+, Ca2+, &K+ from GISP2, Siple Dome, &Taylor Doı
(200-Year Gaussian Smoothed)
GISP2
Siple Dome
Taylor Dome
Na+
Ca2+
K+
Years Before Present
0
10000
20000
30000
40000
50000
60000
70000
80
40
20
800
400
0
10
150
100
50
5

ACTIVITIES AND FINDINGS

Findings:

Major findings include thus far:

1. Ice core proxy for Amundsen Sea Low and hindcasted record.
2. Identification of ENSO impact on West Antarctica.
3. Joint investigation of Siple Dome, Taylor Dome, and Law Dome Holocene records to identify associated features and forcings plus non-associated factors.
4. Chemical signature of pre-Holocene Antarctic rapid climate change events.
5. Holocene record of environmental change (eg., sea ice, volcanism, atmospheric circulation).
6. The major ion series have strong seasonal signals.
7. The major ion series provide histories of volcanic events, marine storminess, katabatic wind events that affect West Antarctica
8. Seasalt series are strongly correlated with SLP fluctuations in the region of the Amundsen Sea Low and surrounding ocean.
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16. Interpretation of the Siple Dome major ion record has been greatly facilitated by US ITASE ice core interpretations.

Training and Development

Training and Development:

a) Several students were/are involved in this project including:

Dr. Karl J. Kreutz (Ph.D. completed June 1998) was involved in the field and laboratory program, spatial analysis studies, and time-series analysis from ice cores. Ph.D. dissertation based data generated from this grant.

Eric A. Meyerson (Ph.D. Student) is involved with processing and laboratory program related to the Siple Dome A-Core and his dissertation will be based on data generated from this grant.

Several M.Sc. students (Eric A. Meyerson, David B. Reusch) and undergraduate work study students (Joseph M. Souney, Kelly A. Bridges, Erin Darrow, Erin Stanisewski, Sarah A Story, Colleen Lynch, Hui Duan, Andrew Dawson, Jeremy B. Smith, Alexander Sirois) were involved in sample processing and laboratory analysis. Additional personnel were also involved in the sample processing:
Andrew Lorrey, Daryl Friedman, Sam Kelley (High School Student; Orono, Maine), Chris Zielinski (High School Student; Bangor, Maine).

b) Data collected as part of this program was and will be used as an integral part of a senior/graduate level course in paleoclimate analysis.

Outreach

Outreach Activities:

a) Public and peer awareness of the program is being promoted by participating in several interviews with newspaper reporters plus public lectures (average 10/year to grammar schools, high schools, and adults) plus invited presentations at scientific conferences.
b) Representation nationally and internationally via presentations and meetings (over past year) by Lead PI P.A. Mayewski at:
Great Bay Rotary Club
Harvard Travellers Club
Boston Bay Group
Osgood Lecture, Wooster College, Ohio
US ITASE High School Teachers Workshop
Public lectures – Boston Museum of Science
IMAGES Meeting, Trins, Austria
AGU

ACTIVITIES AND FINDINGS

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In addition to constructing a longer bipolar comparison between Siple Dome and Greenland, the Siple Dome record helps complete a transect of chemistry sites across the Pacific sector of Antarctica. The quality of these ice cores records (Siple Dome, Taylor Dome, South Pole, Law Dome) allows for detailed survey of the last 1000 years. Variations in these records show climate events within the LIA that have similar timings and structure as seen in the tree ring Carbon-14 residuals (proxy for solar irradiance). There are, however, differences in these cores that most likely arise from the different atmosphere circulation patterns across the Pacific sector of Antarctica.

f. Holocene and Glacial Climate History

The ~98ky glaciochemical record recovered from Siple Dome reveals strong source signals from the ocean (seasalt (ssNa, ssK, ssMg, ssCa, ssCl, ss-sulfate) and biogenic non-ss-sulfate), volcanism (excess-sulfate), remote continental dust (nssK, nssCa), and katabatic flow (nitrate, biogenic nss-sulfate). The strongly calibrated Siple Dome seasonal (Sept-Nov) signature in seasalt species is dominated by the strength (SLP) of the Amundsen Sea Low (ASL). This calibration has predicated a record of the Antarctic Oscillation (AAO): specifically the ASL (West Antarctica) and the East Antarctic High (EAH), East Antarctica. The well-preserved Siple Dome Holocene structure is similar to the GISP2 Holocene (Figure 1) suggesting a strong association between ASL behavior and that of GISP2 proxies for the Icelandic Low (Na) and the Siberian High (K). The pre-

Holocene climate record from Siple Dome (Figure 2) is quite different from other Antarctic records because the glacial age ASL (the major source for marine air) is significantly north of its Holocene position as a consequence of changes in boundary conditions (e.g., size of EAH, sea ice extent, ice sheet configuration, grounding line retreat in Ross Sea at ~75OO years before present). The Little Ice Age expansion and deepening of the ASL is the most dramatic event in the full Siple Dome Holocene-Glacial atmospheric circulation record.

g. Data Synopsis

Ice core processing to date (April 2002):
(a) A-Core—bi-yearly continuous, 0-600m; multi-year continuous 600-1004m; continuous flow analysis, 0-154m.

(b) 1994-Core—continuous flow analysis, 0-150m; bi-yearly continuous, 60-150m; sub-annual continuous, 0-60m.

(c) B-Core—continuous flow analysis, 0-100m; sub-annual continuous, 0-13m.

(d) Hot Water Core—sub-annual continuous, ~2m sections for every ~100m for ~1000m.

Data Archive (April 2002):
All the data has been compiled and archived with the Siple Dome (WAISCores) Science Coordination Office (SCO) at http://waiscores.dri.edu/. After June 2002, this data will be archived at the Antarctic Glaciological Data Center (NSF OPP) at http://nsidc.org/agdc/index.html.

h. Siple Dome A-Core Sample and Sub-Sample Generation

The Siple Dome A-Core was transported from the field to the National Ice Core Laboratory (NICL) situated at the United States Geological Survey in Denver, Colorado. The major ion chemistry (Mayewski, PI) and tephra (Zielinski, PI) ice sections were partitioned as one entire section from the Siple Dome A-core together during the many summer Siple Dome core processing line sessions at NICL and transported back to freezer laboratory facilities at the University of New Hampshire and later, the University of Maine. The major ion chemistry section (3.5 cm by 3.5 cm area section for every meter) was processed with melter head systems that obtained the center of each sample. From this sample, aliquots for cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anions (Cl^-, SO_4^{2-}, NO_3^-) were taken for analyses with ion chromotography. Sub-sample aliquots for methanesulfate (Saltzman, PI) for each sample were taken at this time and sent off. The remaining sample was then used for tephra analyses (Zielinski, PI). The melter head systems produced a sub-sample that was also collected for cosmogenic isotopes (Nishizumi, PI). In addition to this collection process, the cosmogenic isotope samples were treated with nitric acid and a beryllium tracer, and then prepared and shipped to the University of California at Berkeley.

Figure 1.

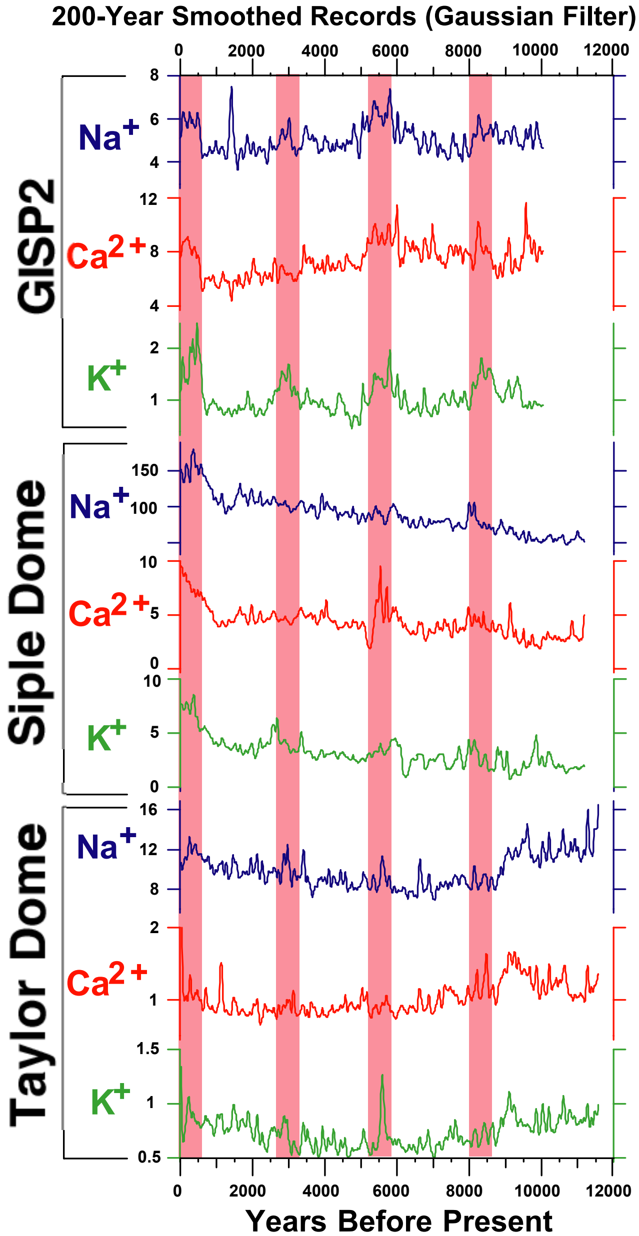
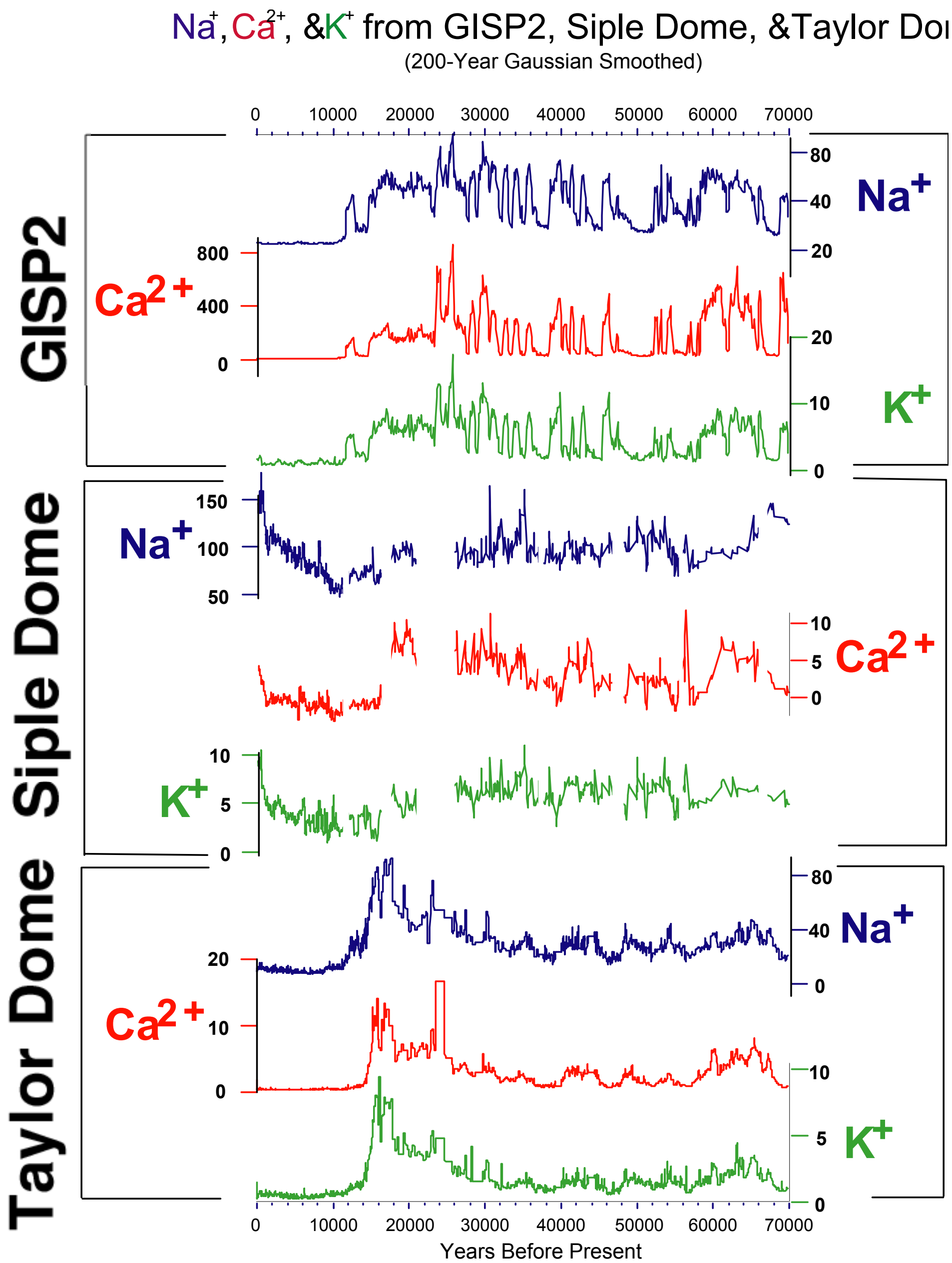

200-Year Smoothed Records (Gaussian Filter)
GISP2
Siple Dome
Taylor Dome
Na+
Ca2+
K+
0
2000
4000
6000
8000
10000
12000
Years Before Present

Figure 2.



Na+, Ca2+, &K+ from GISP2, Siple Dome, &Taylor Do
(200-Year Gaussian Smoothed)
0 10000 20000 30000 40000 50000 60000 70000
GISP2
Na+
80
40
20
Ca2+
800
400
0
20
10
0
K+
Siple Dome
Na+
150
100
50
Ca2+
10
5
0
K+
10
5
0
Taylor Dome
Na+
80
40
0
Ca2+
20
10
0
K+
10
5
0
Years Before Present

ACTIVITIES AND FINDINGS

Findings:

Major findings include thus far:
1. Ice core proxy for Amundsen Sea Low and hindcasted record.
2. Identification of ENSO impact on West Antarctica.
3. Joint investigation of Siple Dome, Taylor Dome, and Law Dome Holocene records to identify associated features and forcings plus non-associated factors.
4. Chemical signature of pre-Holocene Antarctic rapid climate change events.
5. Holocene record of environmental change (eg., sea ice, volcanism, atmospheric circulation).
6. The major ion series have strong seasonal signals.
7. The major ion series provide histories of volcanic events, marine storminess, katabatic wind events that affect West Antarctica
8. Seasalt series are strongly correlated with SLP fluctuations in the region of the Amundsen Sea Low and surrounding ocean.
9. Siple Dome experienced a dramatic increase in marine storminess during the period classically termed the Little Ice Age (LIA; nominally recorded in the literature as occurring from 1350-1900 A.D.
10. The Siple Dome LIA-event has an onset time that is coincident with that of the LIA in the North Atlantic based on a correlation with the GISP2 record.
11. The Siple Dome LIA-like event is the most dramatic (i.e., highest sustained chemical concentrations) climate seen in the Siple Dome Holocene-Glacial (~98ky BP) glaciochemical record
12. The SD Holocene record contains evidence of many of the Holocene rapid climate change events seen in the GISP2 Holocene record and a gobal assemblage of other Holocene records
13. The Siple Dome Holocene trend in ion series is related to insolation during the deposition of seasalt (September-November).
14. The Siple Dome Holocene ion record offers important insights into global climate change when viewed in the context of a global array of Holocene climatic records.
15. The pre-Holocene ion record has both close parallels with the Taylor Dome pre-Holocene record and notable dissimilarities. The dissimilarities indicate that the Siple Dome region was not dominated by the Amundsen Sea Low influences during the pre-Holocene as a consequence of significant expansion of sea ice, local ice surface topography, regional ice surface topography, or continental scale differences in atmospheric circulation.
16. Interpretation of the Siple Dome major ion record has been greatly facilitated by US ITASE ice core interpretations.

Training and Development

Training and Development:

a) Several students were/are involved in this project including:

Dr. Karl J. Kreutz (Ph.D. completed June 1998) was involved in the field and laboratory program, spatial analysis studies, and time-series analysis from ice cores. Ph.D. dissertation based data generated from this grant.

Eric A. Meyerson (Ph.D. Student) is involved with processing and laboratory program related to the Siple Dome A-Core and his dissertation will be based on data generated from this grant.

Several M.Sc. students (Eric A. Meyerson, David B. Reusch) and undergraduate work study students (Joseph M. Souney, Kelly A. Bridges, Erin Darrow, Erin Stanisewski, Sarah A Story, Colleen Lynch, Hui Duan, Andrew Dawson, Jeremy B. Smith, Alexander Sirois) were involved in sample processing and laboratory analysis. Additional personnel were also involved in the sample processing:
Andrew Lorrey, Daryl Friedman, Sam Kelley (High School Student; Orono, Maine), Chris Zielinski (High School Student; Bangor, Maine).

b) Data collected as part of this program was and will be used as an integral part of a senior/graduate level course in paleoclimate analysis.

<u>Outreach</u>

Outreach Activities:

a) Public and peer awareness of the program is being promoted by participating in several interviews with newspaper reporters plus public lectures (average 10/year to grammar schools, high schools, and adults) plus invited presentations at scientific conferences.
b) Representation nationally and internationally via presentations and meetings (over past year) by Lead PI P.A. Mayewski at:
Great Bay Rotary Club
Harvard Travellers Club
Boston Bay Group
Osgood Lecture, Wooster College, Ohio
US ITASE High School Teachers Workshop
Public lectures – Boston Museum of Science
IMAGES Meeting, Trins, Austria
AGU