Greenland Ice Sheet Project Two
GISP2

GISP2 Notebook

Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
No. 2, Spring 1992

GISP2 Update

As of camp closing September 14, 1991, the GISP2 program had reached a depth of 1510 meters, recovering ice with an age of approximately 8000 years BP. During the 1991 season, discrete and continuous samples were taken to a depth of 719 meters (approximately 3000 BP) and from 1372 to 1510 meters. Between 719 meters and 1372 meters, the brittle ice zone was encountered and sampling over this depth range was postponed until the 1992 field season to assure sufficient time for core relaxation and thus facilitate sampling of this section.

Since the last issue of the Notebook, we have convened GISP2 science working meetings at Boulder, Lake Tahoe and Miami. These sessions have been focused primarily on preliminary reporting of data and interpretations plus planning for the next year's field season. The figure on this page is a generalized example (50 year smoothing) of the type of multi-disciplinary data sets now evolving from GISP2. From this record it is clear that even relatively small (by comparison with those to be encountered in the 200,000 year record) climatic events of the last millennium are sensitively recorded by several core properties. Detailed interpretations of the last 2000 years of the GISP2 paleo-environmental ice-core record calibrated with historical and instrumental records will provide the necessary analog for interpreting the record in pre-instrumental and pre-historic time.

In addition to our group meetings, GISP2 researchers have presented results of their work at several national and international meetings and have published several articles. Abstracts of published papers and titles of those in press and in review appear in this Notebook.

The Atmospheric Sampling Facility, 30 km upwind from GISP2 Camp, has continued to grow. There are now 13 sampling lines in operation powered by 6 kw of solar panels. Experiments by, or on the behalf of, 30 U.S. and European investigators are being carried out to develop our understanding of the atmospheric environment of the Summit region.

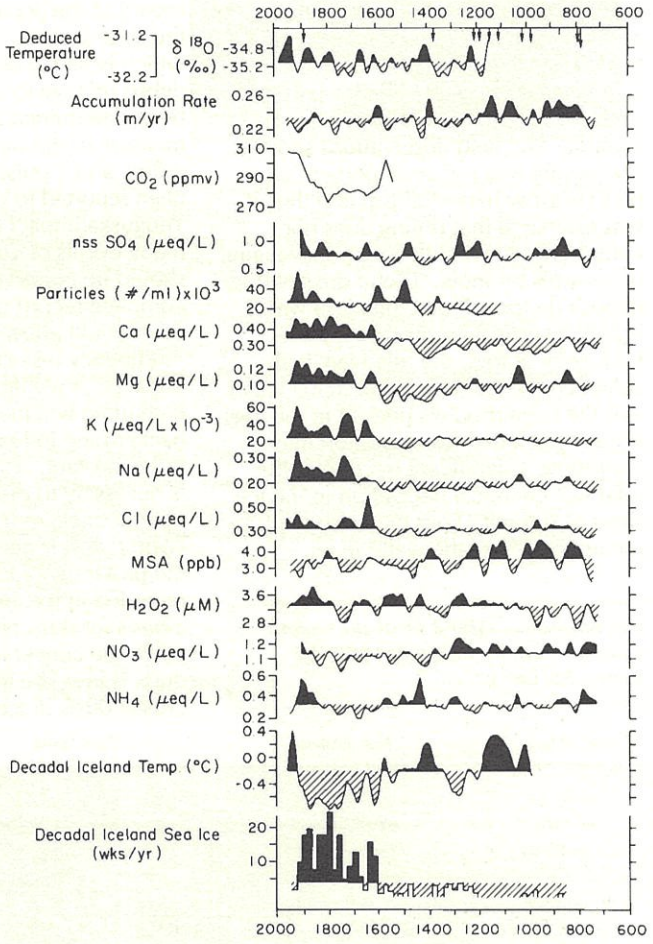
As of the 1991 field season , GISP2 has welcomed several new scientific efforts. These new projects are summarized in this issue of the Notebook.

We continue to enjoy and appreciate the interaction with our colleagues to the east in the GRIP (Greenland Ice Core Project) camp. A joint GRIP - GISP2 scientific workshop is being planned for Spring, 1993.

Finally, as the 1992 field season rapidly approaches and we look to the future, we should not forget the hard work and dedication that has already gone into GISP2 and the individuals who have contributed to our success (see List of Participants, page 9).

We are proud of the achievements won by the efforts of all of the individuals who developed, constructed, and operated the drill, the science trench and the camp, those who provided support from Sondrestrom and the goodhearted dedication of the 109th ANG who maintained the flow of equipment and personnel necessary to a successful field season.

Paul A. Mayewski -
Director and Chief Scientist, GISP2 Science Management Office
Michael C. Morrison -
Associate Director, GISP2 Science Management Office



Examples of some of the properties measured using the GISP2 core subjected to a 50 year smoothing. The results suggest that even relatively minor climatic events (compared to those expected in the remainder of the ~200,000 year record), such as the Medieval Warm Period (MWP) and the Little Ice Age (LIA), are sensitively recorded. (The MWP extended from approximately 1000 A.D. to between 1350 or 1450, and was followed by the LIA until approximately 1900.) For general reference, decadal values of temperture approximated from Icelandic sea ice frequency (after Bergthorsson, 1969) also appear in the figure. GISP2 temperature modeled from oxygen isotopes reveals a relatively subdued temperature effect at this site for the LIA. Accumulation rate is generally lower during the LIA than the MWP. Carbon dioxide values may dip slightly during the LIA. Nss sulfate, primarily reflecting volcanic input as plotted here, does not appear to be a major forcing agent on climate. Dust (via particles, calcium, magnesium and potassium) and marine (via sodium, chloride and MSA) sources and/or transport to the site increased during the LIA. Nitrate sources (eg lightning, soil exhalation) decreased during the LIA. Finally ammonium, primarily reflecting biomass burning as plotted here, has peaks which roughly parallel the onset and end of the LIA (decay and growth of biomass, respectively). CRREL, U of MIAMI, PSU, Scripps, UNH, UWA.

New Project Abstracts

Assessment of Ice Particle Growth and Scavenging Processes at Summit, Greenland

R.D. Borys, Desert Research Institute, University of Nevada, Reno

Collections of snow crystal replicas and cloud water made at the GISP2 ice coring site in Greenland were analysed to ascertain the mode of ice crystal growth and aerosol scavenging. Ice particle sizes and habits, cloud water chemistry and total snow chemistry were used to estimate the importance of ice particle riming on chemical wet deposition at summit. The field observations showed that riming was not an important ice particle growth mechanism and thus it was estimated that riming does not contribute significantly to the scavenging of aerosols by snow. Cloud droplet (fog) deposition (occult precipitation) was briefly investigated. Because of the frequency of fogs, the relatively high solute concentrations found in fog water and the large droplets present in the fogs it was concluded fog depositon may contribute a significant fraction of the total wet chemical deposition to the ice sheet at summit. Fogs may also contribute up to 10% of the water mass.

Cover photo : GISP2 Drill dome and science trench entryway 1990 by Lynne Fosberry

The Record of Ir and Os-Isotopes in Polar Ice

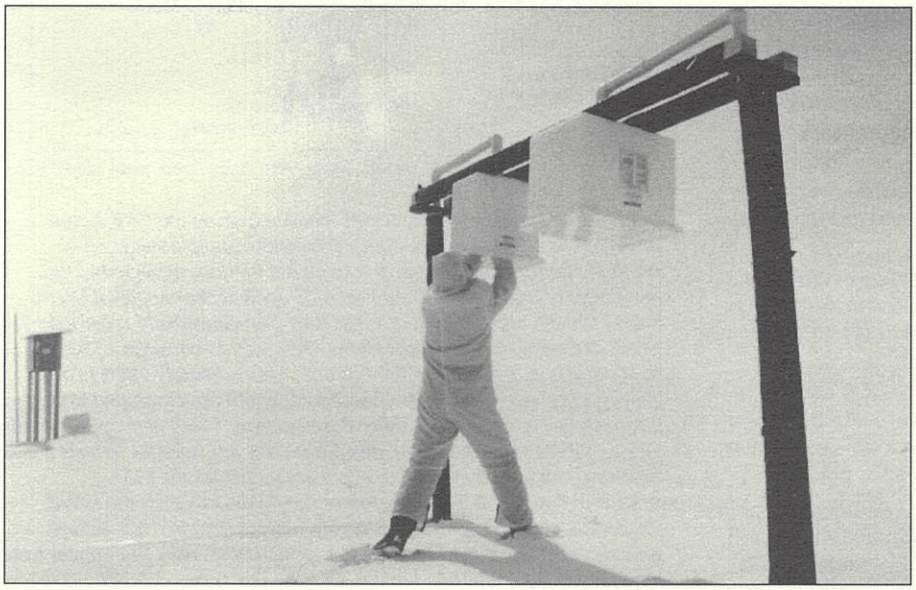
E.A. Boyle, Massachusetts Institute of Technology

Large meteoritic impacts probably exert important modifications of global climates and ecosystems, but the size and frequency of these events is not well established. Polar ice cores preserve a record of the accretion of materials from the solar system. The element iridium, which is highly enriched in extraterrestrial debris relative to crustal materials, has been determined in Antarctic ice as a measure of the steady state cosmic debris influx, and a pulse of cosmic iridium has been reported to coincide with the 1908 Tunguska impact event. It is likely that many events of Tunguska magnitude should be preserved in a deep ice core. A complete record of Ir in a long polar ice core would allow us to determine the size - frequency history of previous cosmic impacts. It would also allow us to determine whether the more uniform background influx of small particles is truly constant. To observe these pulses, it is necessary to distinguish them from normal background crustal, volcanic, and cosmic dust Ir deposition. A study of Ir in the proximity of known volcanic events recorded in ice cores is needed to provide a basis for this correction. Similarly, while the concentration of Ir in crustal dusts is low, the total concentration of crustal dusts in ice cores is high relative to the abundance of cosmic dusts. To allow for the possible influence of these high concentrations of crustal dusts on the cosmic Ir signal, it is necessary to examine the Ir concentration in relation to changes in the terrestrial dust record. Further confirmation of the extraterrestrial nature of Ir can be provided by measurement of the isotopic composition of osmium. Due to fractionation of radioactive parent ^{187}Re from radiogenic daughter ^{187}Os during magmatic processes, the ratio of $^{187}Os/^{186}Os$ is 400 in crustal rocks while it is only 3 in meteorites. Hence variation of the osmium isotope ratio can help to distinguish cosmic (or mantle - derived) Os from meteoritic Os. We propose to undertake these studies as an ancillary part of the ongoing GISP2 ice core program.

Atmospheric Transport and Deposition of Chemical Constituents at the GISP2 Ice Core Site

J-L Jaffrezo, C.I. Davidson, and M.J. Small, Carnegie Mellon University

GISP2 involves acquisition of a deep core to bedrock from the Summit region of Greenland. The core will provide a detailed record of some 200,000 years, yielding information on the earth's



At the atmospheric sampling site (ATM) great effort is taken to sample air that has not been affected by the GISP2 camp or other sources of local contamination. This site may be the "cleanest" atmospheric sampling station in the world. Here a researcher changes a filter. The aerosols in the air, trapped on this filter, will be analyzed for their trace metal content. (Photo: Jack Dibb)

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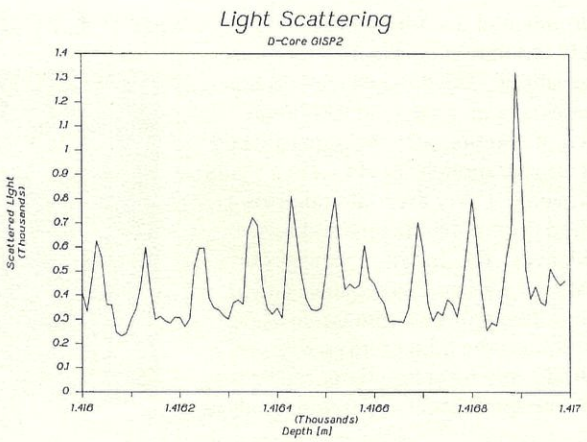
The GISP2 Science Management Office is the coordinating office for the GISP2 project. It is responsible for coordinating scientific and logistical activities of GISP2. Paul Mayewski is the Director of the SMO and Michael Morrison is the Associate Director. Direct correspondence to:

Michael Morrison
GISP2 Science Management Office
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Durham, NH 03824-3525
Phone: 603-862-1991
Fax: 603-862-2124
OMNET: "GISP2"
Internet: "smo@unh.edu"

Two committees provide oversight of GISP2:
Executive Committee
Pieter Grootes
Paul Mayewski (Chairman)
Martin Wahlen
Advisory Committee
Charles Bentley
Wallace Broecker (Chairman)
George Denton
John Imbrie

Laser Light Scattering



Laser-light scattering output for section of Summit core . Annual peaks in Dust concentration are easily seen, and aid in dating the core. SUNYB.

geologic history, climate change, and variations in chemical composition of atmospheric constituents. This project will investigate transport of chemical species in the atmosphere from source regions to the Greenland Ice Sheet at Summit, in order to better interpret data from the GISP2 core. There are three specific objectives. First, source regions and atmospheric pathways for the chemical constituents reaching Summit will be identified. Possible changes in characteristics of the air masses during transport will be explored. Second, incorporation of these chemical species into precipitation at Summit will be investigated, in order to determine the mechanisms and rates of deposition during snowstorms. Finally, changes in the chemical composition of the Ice Sheet after snowfall will be identified. These changes include additional input of chemical species by dry deposition onto surface snow, and also redistribution of the species within the snowpack. The objectives will be achieved by a program that incorporates field work, laboratory analyses, and computer modeling. The field work includes collection of aerosol, air, and precipitation samples; these will be analyzed in the laboratory for a wide variety of species such as anions and cations, trace elements, carbon compounds, and trace gases. Computer modeling work includes development of a climatology for Summit as well as mathematical modeling of the deposition processes. The results of this project will identify the most important source regions, atmospheric pathways, and deposition mechanisms influencing chemical constituents in the deep core. This in turn will help separate the effects of variations in airborne concentration and variations in deposition rate in influencing these constituents in the core. The results will also improve our ability to derive relations between snow accumulation rate and concentrations throughout the core.

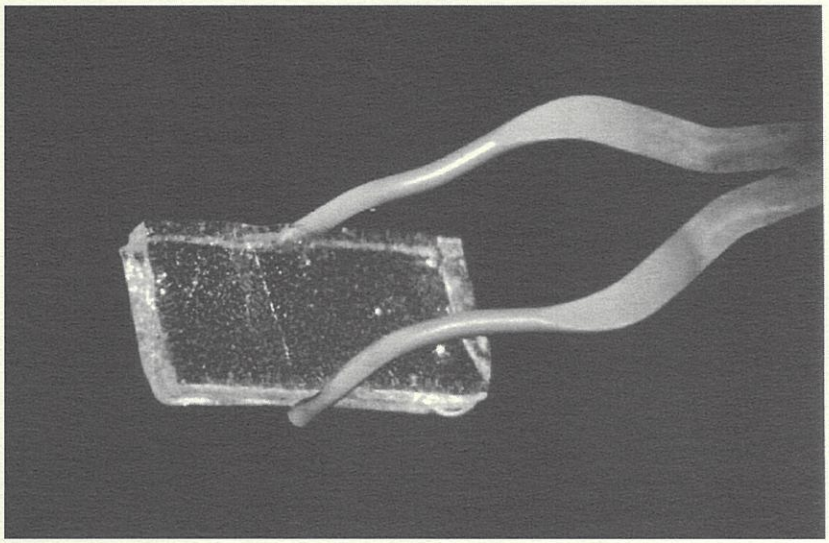
Continuous Measurements of Dust Concentration Along The Summit Ice Core

M. Ram and M. Illing, SUNY Buffalo

We have designed and built a 90° laser-light-scattering (LLS) instrument for measuring the dust concentration along an ice core. A specially designed heater melts ice along the core and meltwater is passed into an optical cell where the dust concentration is measured by scattering laser light off the meltwater and observing the light that is scattered at 90°. At present, the instrument is capable of a resolution of 2 mm which will allow us to observe sharp seasonal dust peaks even when the yearly accumulation is as small as 1 cm of ice core. Thus, we will be able to date the core down into the glacial stages with no difficulty. Indeed, we have found that the seasonal dust peaks become sharper and more distinct as the depth increases. At present, we are able to measure 12 m of ice in a 24 hr period. This is not sufficient to keep up with core processing and the ice that is not measured in the field has to be measured in our lab in Buffalo.

In addition to measuring seasonal dust peaks, we are also able to measure changes in background dust levels. We have already observed two very significant changes in dust background levels during the holocene each lasting approximately fifteen years. We will look for more events of this kind and will analyze the mineralogy and size of the dust that is associated with them. This will help us understand the origin and nature of these unusual increases in dust levels.

We are developing an instrument for carrying out laser-light-scattering measurements directly on ice. We tested the technique in the summer of 1991 and it looked very promising. We will have an instrument ready for use in the summer of 1992. Direct measurements on ice are much faster (it is possible to process one meter in 10 - 15 minutes) and non-destructive. In addition, we believe that we will be able to measure other properties of the ice by this method and not just changes in dust concentration. Since many properties of ice change as it ages, these laser scattering measurements on ice will have to be done in the field.



A piece of ice that has been cut from the core and cleaned. Bubbles of air trapped in the ice can be seen. These bubbles contain samples of the ancient atmosphere and are analysed to create a time series of atmospheric composition changes, including CO_2. (Photo : Michael Morrison)

Paleothermometry by Control Methods: The Inference of Past Climate From the GISP2 Temperature Profile

E.D. Waddington, D.R. MacAyeal, and J. Firestone, University of Washington

One of the major goals of glaciological research is the inference of past climate from ice cores. One way to make this inference is through the measurement and analysis of the temperature-depth profile at the drill site. Temperature analysis is independent of isotopic techniques, and thus can provide an independent check on interpretations of isotopic signals (e.g., was there a Younger Dryas signal in the Dye-3 oxygen-isotope profile, or does the oxygen-isotope profile merely reflect the abundance of glacial meltwater in the North Atlantic?)

Despite sophisticated understanding of the physics of heat transfer in ice sheets, analysis of temperature-depth measurements has been rather crude. Highly developed temperature models are used in a trial-and-error mode to select environmental histories which yield the best fit to today's ice-sheet temperature observations. We have developed the rudiments of an analytical technique which, if coupled with the sophisticated heat transfer models, could yield a major improvement over the trial-and-error method (it is more efficient and less subjective). This method comes from a branch of applied mathematics called control theory (the precise name of our technique is the adjoint trajectory method). We have tested our method by repeating the Dye-3 temperature analysis.

We need to develop the adjoint - trajectory method for the inference of past climate to a greater degree before it can be applied to the GISP2 data . We anticipate that application of our method to the GISP2 data will yield a surface - temperature history for the Greenland Ice Sheet (over the Holocene at least) that is independent of all isotopic techniques.

(More abstracts on page 8)

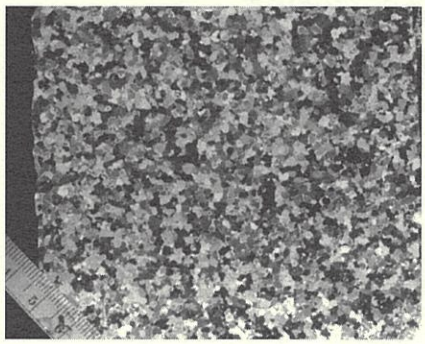
GISP2 Principal Investigators

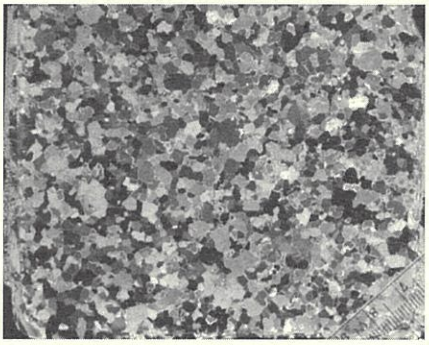
Alley, Richard	Penn State Univ.
Barry, Roger	Univ. of Colorado
Armstrong, Richard	
Bender, Michael	Univ. of Rhode Island
Bolzan, John	Ohio State Univ.
Boyle, E.	MIT
Gow, Tony	Cold Regions Research and Engineering Lab
Meese, Debra	
Grootes, Pieter	Univ. of Washington
Stuiver, Minze	
Hodge, Steve	U.S. Geological Survey, St. Olaf College
Mayewski, Paul	Univ. of New Hampshire
Nishiizumi, Kunihiko	U.C. San Diego
Arnold, James	
Finkel, Robert	Lawrence Livermore Laboratory
Ram, Michael	SUNY Buffalo
Saltzman, Eric	Univ. of Miami
Stearns, Charles	Univ. of Wisconsin
Taylor, Ken	Desert Research Institute
Waddington, Edward	Univ. of Washington
Wahlen, Martin	Scripps Inst. of Ocenaography
Broecker, Wallace	Lamont-Doherty Geological Observatory
White, James	Univ. of Colorado
Wilson, Alex	Univ. of Arizona
Donahue, D. J.	
Zielinski, Greg	Univ. of New Hampshire

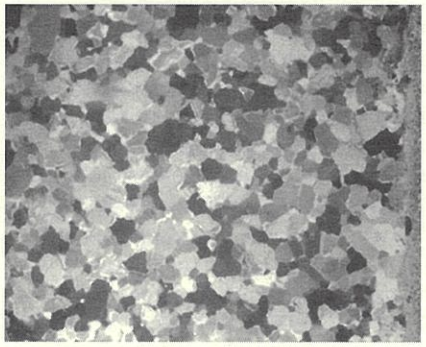
ATM Principal Investigators

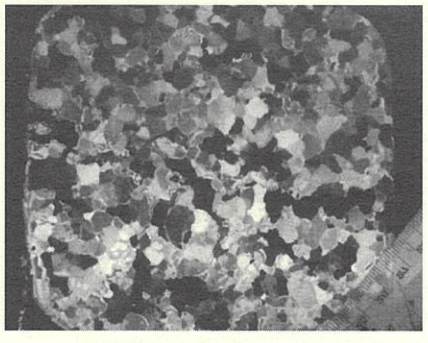
Borys, Randy	Desert Research Institute
Davidson, Cliff	Carnegie Mellon Univ.
Dibb, Jack	Univ. of New Hampshire
Mosher, Byard	Univ. of New Hampshire

Ice Crystal Growth









These four horizontal thin sections taken at 92, 160, 333, and 591 meters show a steady increase in crystal size with depth due to normal grain growth in the core. CRREL, PSU.

Papers Published to Date

Recent Warming in Central Greenland?

Alley, R. B., and Koci, B. R.

Annals of Glaciology, Vol. 14, 1990

GISP2 89-01

Recent Warming has occurred in near-surface firn in Central Greenland, as shown by analysis of a 217 m temperature profile from the GISP2 site. However, this warming falls within the range of natural variability and provides no clear evidence of a greenhouse signal.

Summertime formation of depth hoar in central Greenland

Alley, R. B., E. S. Saltzman, K. M. Cuffey, and J. J. Fitzpatrick

Geophysical Research Letters, Vol. 17, No. 12, Pages 2393-2396, December 1990

GISP2 90-03

Summertime solar heating of near-surface snow in central Greenland causes mass loss and grain growth. These depth hoar layers become seasonal markers which are observed in ice cores and snow pits. mass redistribution associated with depth-hoar formation can change concentrations of immobile chemicals by as much as a factor of two in the depth hoar, altering atmospheric signals prior to archival in ice. For methanesulfonic acid (MSA) this effect is not significant because the summer maximum does not coincide with the density minimum, and the amplitude of the annual (MSA) signal is more than a factor of ten.

Beryllium-7 and Lead-210 in the Atmosphere and Surface Snow over the Greenland Ice Sheet in the Summer of 1989

Dibb, J. E.

Journal of Geophysical Research, Vol. 95, pp.22407-22415, Dec.20,1990

GISP2 90-01

The concentrations of ^{7}Be and ^{210}Pb were measured in surface air and fresh and aging snow samples from Summit (72° 20' N, 38° 45' W) and Dye 3 (65° 10' N, 44° 45' W) Greenland, during June and July, 1989. The aerosol concentrations of these radionuclides showed rapid variations at both sites, but were nearly twice as high, on average, at Summit. Concentrations in the 16 fresh snowfall events that were sampled also showed wide variability, but the averages were the same at the two sites.

The apparent difference in air-snow fractionation and the lack of coherence in the concentration in air time series between the two sites indicate previously unsuspected complexity in atmospheric dynamics over the ice sheet. Improved understanding of atmospheric processes, and how the results of those processes are recorded in snow and ice, are crucial for full interpretation of the information about past atmospheric chemistry and climate contained in the snow and ice of glaciers around the world.

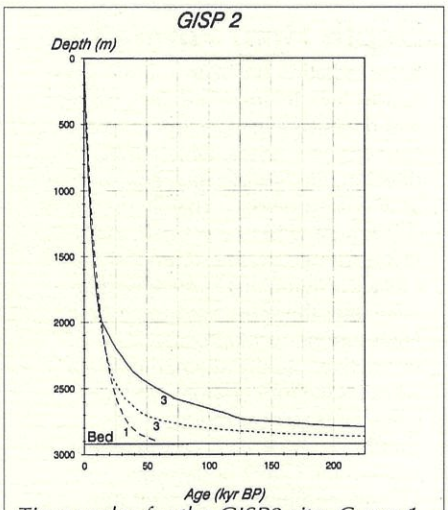
The Accumulation of Pb - 210 at Summit, Greenland since 1855

Dibb, J.E.,

Tellus (1992), 448, 72-79

GISP2 90-04

Detailed (202 samples) profiles of total beta and Pb - 210 activity were determined from a 32 m firn core collected at the GISP2 site (72° 20' N, 38° 45' W) near Summit, Greenland in 1989. The beta radioactivity profile verifies year by year dating based on recognition of annual hoar layers back to 1955, and lends a high degree of confidence to the 74 year age assigned to the bottom of the core by this stratigraphic dating technique. The decay corrected activity of Pb - 210 at the time of deposition shows considerable short term variability, but no clear seasonal or annual periodicity. Pb - 210 activity in surface snow at this site has averaged 0.7 pCi kg^{-1} since 1927, but the period 1915 - 1927 is characterized by a steady decline from higher levels. The average annual accumulation of Pb - 210 has markedly declined since at least 1870. Similar observations at Dye 3 suggest that Pb - 210 accumulation has decreased throughout this century over much of the Greenland Ice Sheet. If the records of Pb - 210 in the firn on the Greenland Ice Sheet are mainly reflecting the northern hemisphere atmospheric burden of Pb - 210, these results will demand careful reassessment of Pb - 210-based radiochronologies. However, our current lack of understanding of the linkages between atmospheric and snow chemistry makes the widespread applicability of these findings an open question.



Time scales for the GISP2 site. Curve 1 shows the steady state Nye-Haefeli time scale. Curves 3 are derived from finite element modeling. Dashed curves are for steady state. Solid curve was derived using mass balance history. From; Predicted Time Scales for GISP2 and GRIP Boreholes at Summit, Greenland. C. Schott, E.D. Waddington and C. Raymond. In press, Journal of Glaciology.

Acknowledgements

Permission to work in Greenland is provided by The Commission for Scientific Research in Greenland and the governments of Denmark and Greenland and is gratefully acknowledged.

GISP2 is made possible by the efforts of: the 109th Air National Guard from Scotia, NY providing ski-equipped C-130 airlift support; the National Science Foundation, Division of Polar Programs providing funding for the individual science projects and the GISP2 Science Managment Office (Grant No. DPP-8944997); the Polar Ice Coring Office at the University of Alaska Providing logistical and drilling support; and collaboration with our colleagues of Eurocore and GRIP.

Butyl Acetate, an Alternative Drilling Fluid for Deep Ice Coring Projects

Gosink, T. A., Kelley, J .J., Koci, B. R., Burton, T. W., and Tumeo, M. A.

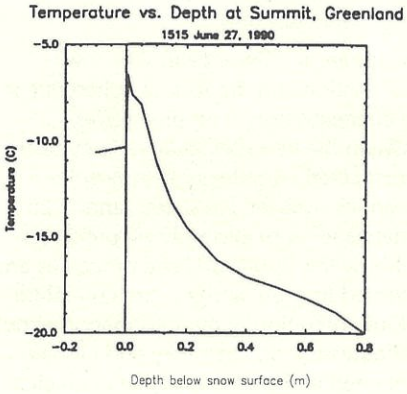
Journal of Glaciology, Vol. 37, No. 125, 1991, pp 170 - 176

GISP2 90-02

Deep-drilling operations in glaciers require a fluid to maintain hydrostatic equilibrium and prevent closure due to plastic flow of the ice. Many past practices have employed various fluid mixtures using fuel oil as the base. The case for butyl acetate is presented here as an adequately dense and environmentally sage drilling fluid. Results from the 1990 drill season are highly favorable.

Depth Hoar Formation

Solar radiation on clear summer days causes high temperatures (see figure) and diffusive mass loss from near-surface snow layers, which then develop into low-density, coarse-grained depth hoar. The alternation of depth hoar with fine-grained, dense layers formed during summer storms creates a signal that is recognizable even after the snow has turned to ice. Each summer is marked by these distinctive, rapidly alternating strata, whereas ice formed from winter snowfall is more uniform.



Careful study of ice cores on a light table in the GISP2 undersnow laboratory allows us to count the distinctive summer layers. We then compare these data with annual layer counts from electrical conductivity, dust concentration, and other parameters, to resolve any ambiguities. The result is highly accurate dating of the ice core, plus a record of how much snow fell per year and of what season is represented by any given ice sample. CRREL, PSU.

A Glaciochemical Survey of the Summit Region, Greenland

Mayewski, P.A., M. J. Spencer, M. S. Twickler, and S. Whitlow

Annals of Glaciology, Vol.14, 1990

GISP2 90-07

Spatial representativeness and an understanding of controls on chemical species distribution are essential requirements of any significant ice core investigation. Snowpit studies provide an essential tool in this process. In preparation for the central Greenland deep drilling effort a series of snowpit was sampled in detail for oxygen isotopes, major anions, major cations, total acidity and radionuclides. The results of this sampling program are used to define: (1) the chemical composition of the snow in the region, (2) the input timing and spatial distribution of major chemical species, (3) the potential dependence of species concentration on accumulation rate, and(4) the signal characteristics identifiable In the region over the last few years.

Volcanic Ash from the 1362 A.D. Oræfajokull Eruption (Iceland) in the Greenland Ice Sheet

Palais, J. M., Taylor, K., Mayewski, P.A. and Grootes, P.

Geophysical Research Letters, Vol.18, No. 7, pp 1241-1244, July 1991

GISP2 90-09

A continuous record of electrical conductivity measurements (ECM) was made on site during the drilling of a 200 m ice core at Summit, Greenland and was used to identify horizons in the ice that might be linked to volcanic eruptions. In one detailed section that we studied a large peak in the number of particles, two orders of magnitude above the background, was measued. The particle peak was not associated with an ECM peak, however. The particles were identified as volcanic ash on the basis of both particle morphology and chemical composition. The ash composition suggests an explosive rhyolitic eruption and is believed to have originated from Oræfajokull in Iceland in1362 A.D.

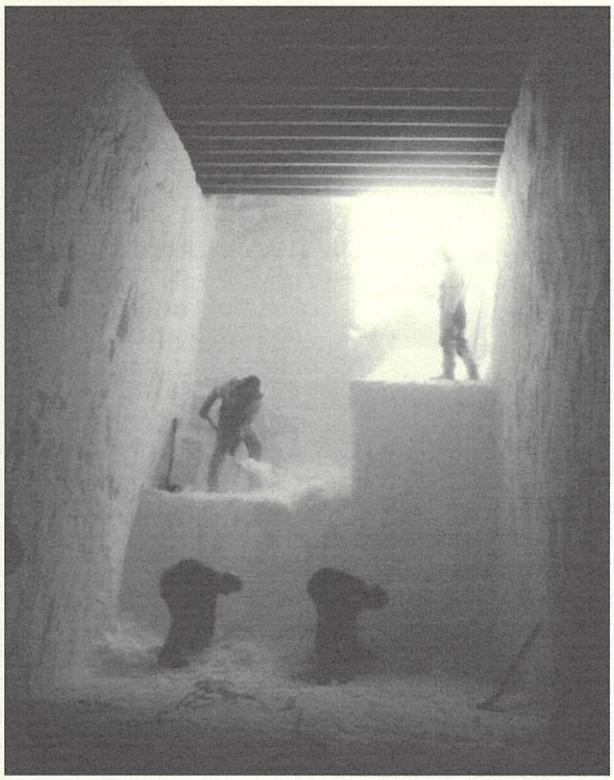
Initial measurements of $C0_2$ concentrations (1530 to 1940 AD) in air occluded in the GISP2 ice core from central Greenland

Wahlen, M., D. Allen, B. Deck and A. Herchenroder

Geophysical Research Letters, Vol. 18, No. 8, Pages 1457-1460, August 1991

GISP2 91-03

Initial measurements of CO_2 in the air of bubbles in the GISP2 (Greenland Ice Sheet Project Two) ice core were performed using a dry extraction technique and tunable diode laser absorption spectroscopy. The record spans the years 1530 to 1940, and includes part of the little ice age. Absolute dating of the air was obtained from the location of the $^{14}CO_2$ bomb peak in the bubble air, relative dating from the seasonal variations of $H_2{}^{18}O$. The results for preindustrial times indicate constant atmospheric CO_2 levels of 280±5 ppmv between 1530 and 1810 AD. Thereafter the concentrations rise rather abruptly. The record smoothly connects to the direct Atmospheric observations from Mauna Loa.



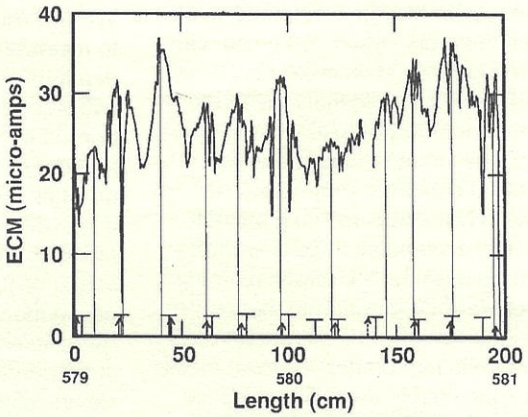
Lab and core processing space was created at the GISP2 site by digging large trenches in the snow. Photo: Mark Twickler

Papers in Press

Author	Title
Alley, Richard B.	Flow-Law hypotheses for ice-sheet modeling (Journal of Glaciology)
Dibb, Jack E., Jaffrezo, Jean-Luc and Legrand, Michel	Initial findings of recent investigations of air-snow relationships in the Summit Region of the Greenland Ice Sheet (Journal of Atmospheric Chemistry)
Fiacco, Joseph R. Jr., M.S.Germani, J.M. Palais, P.A. Mayewski, P.Grootes, S.M. Drummey and S. Whitlow	Atmospheric conditions following the 1783 eruptions of Lakagigar, Iceland and Asama, Japan as interpreted from a Greenland ice core (Bulletin of Volcanology)
Fiacco, R.J., J.M. Palais, M.S. Germani, P.A. Mayewski, S.M. Drummey	Evidence of a prehistoric Mt. St. Helens eruption in a Greenland ice core (Quaternary Research)
Palais, J. M., M.S. Germani and G.A. Zielinski	Inter-hemispheric transport of volcanic ash from the 1259 A.D. volcanic rruption to the Greenland and Antarctic Ice Sheets (Geophysical Research Letters)
Whitlow, S., P.A. Mayewski, and J.E. Dibb	A comparison of major chemical species input timing and accumulation at South Pole and Summit Greenland. (Atmospheric Environment)

Core Dating

This plot (579 - 581 meters) shows how annual layer thickness, and thus dates, are determined for the ice core. The plotted line is electrical condictivity (ECM). The arrows indicate mid-summer



levels based on visual stratigraphy, the "T's" represent laser-light scattering peaks or summers and the straight lines indicate ECM peaks or summers. CRREL, DRI, PSU, SUNYB.

Papers in Review

Author	Title
Cuffey, Kurt and others	Toward using borehole temperatures
Mayewski, P. A., G.Holdsworth, M. J. Spencer, S. Whitlow, M. Twickler, M. C. Morrison, K. K. Ferland, and L. D. Meeker	Ice core sulfate from three Northern Hemisphere sites: Source and temperature forcing implications
Mayewski, P. A., L. D. Meeker, M. C. Morrison, M. S. Twickler, S. I. Whitlow, K. K. Ferland, M. R. Legrand, and J. P. Steffensen	Greenland ice core "signal" characteristics offer expanded view of climate change
Weidner, George A., and Charles R. Stearns	A two year record of the climate on the Greenland Crest from an automatic weather station

The Recovery and Dating of Carbon Dioxide in Polar Ice Cores

Wilson, A. T. and Donahue, D.J.

Nuclear Instruments and Methods in Physics Research, B52(1990), 473-476

GISP2 89-02

A new method is described for recovering trapped carbon dioxide from polar ice cores. The ice is sublimed under vacuum, and water vapor and carbon dioxide are collected at appropriate cold traps. The application of this method to obtain carbon dioxide from a specific ice core, the conversion of that carbon dioxide to graphite, and the measurement of radiocarbon in the carbon dioxide are described in detail. The potentialities and problems of the method are discussed.

AMS carbon-14 dating of ice: progress and future prospects

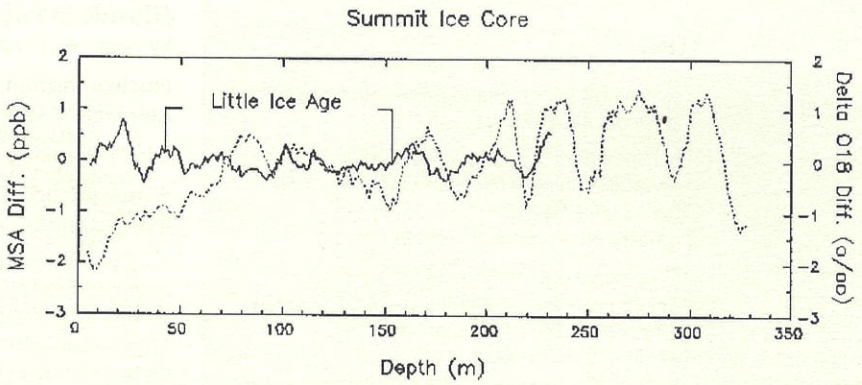
Wilson, A. T. and Donahue, D.J.

Radiocarbon, Vol 31, No.3, 1989, pp. 579-584

GISP2 90-06

The "sublimation technique" for the recovery of carbon dioxide from ice samples and the conversion of the recovered carbon dioxide into graphite for AMS dating will be described, together with its use in some applications. The technique involves placing the ice sample in a carefully degassed glass vacuum system, "cleaning" the ice by removing the outer few millimeters by sublimation, then subliming the ice completely using infrared lamps as an energy source. The gases evolved from the subliming ice first pass through a trap at -80°C to remove water. The remaining gases pass through a trap immersed in liquid nitrogen where the carbon dioxide is recovered. The gases which pass the liquid nitrogen trap are trapped on molecular sieve held at liquid nitrogen temperatures. In our apparatus we can sublime a 3 kg sample of ice core in 18 hours. We measure the quantity of water sublimed, the amount of air and carbon dioxide recovered and the ^{14}C content of the carbon dioxide. From these data we can calculate the altitude of the ice sheet and the CO_2 concentration of the atmosphere at the time given by our ^{14}C date. We have run ice samples as small as 1 kg in the "bomb pulse" zone where the activity is high and the spatial resolution of the core is of concern. The future prospects for the technique look promising and we ultimately hope to be able to date polar ice cores back in time as far as is achieved by AMS dating of more conventional methods.

MSA and ^{18}O



MSA and $\delta^{18}O$ in Summit ice cores. The data shown are the differences between the measured values and the mean, smoothed using a 10 meter running average. Note the pronounced 100-year cycle in MSA, which disappears at the onset of the Little Ice Age (1450-1880). The same cycle is apparent in $\delta^{18}O$, suggesting a relationship between local climate and deposition of biogenic sulfur at Summit. U of Miami, UWA.

More New Project Astracts

Transport and Deposition of Trace Elements to the Greenland Ice Sheet

B.W. Mosher, Complex Systems Research Center, University of New Hampshire

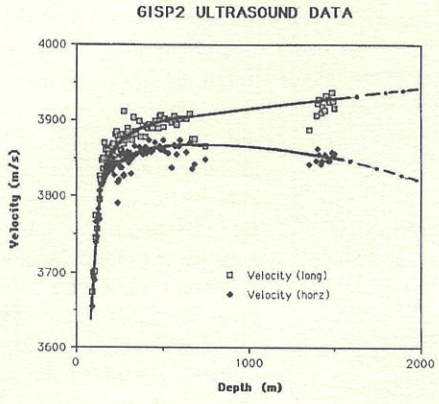
Trace element records preserved in high latitude glaciers such as the Greenland Ice Sheet have the potential to tell us much concerning regional and global scale atmospheric and paleoatmospheric chemistry. Historical information concerning the timing and magnitude of anthropogenic emissions, volcanic eruptions, and climatic change is contained in this record. Before this record can be fully and accurately interpreted we must understand the link between atmospheric composition and snow chemistry. The establishment of an atmospheric sampling program as part of GISP2 provides an excellent opportunity to conduct studies of wet depositional processes active in the high Arctic. This investigation will provide measurements of aerosol and concurrent snow elemental composition with which possible fractionation processes may be examined. In addition this work, when combined with meteorological air mass trajectory analysis, will help to identify the types, locations and transport pathways of contaminants found in the ice sheet. Trace metal data from summer snow samples, when compared with annual trace metal accumulation data, will also allow us to examine the seasonal timing of net chemical deposition to the ice sheet. Additionally, this information will be of value in interpreting the trace metal record contained in the GISP2 deep ice core.

Cosmogenic Radionuclides in the GISP2 Ice Core: ^{10}Be, ^{26}Al, and ^{36}Cl

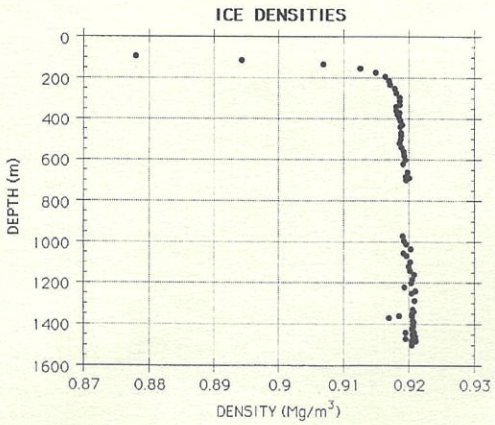
K. Nishiizumi, J.R. Arnold, and R.C. Finkel, University of California at San Diego and Lawrence Livermore National Laboratory

We will use accelerator mass spectrometry to measure ^{10}Be, ^{26}Al, and ^{36}Cl at selected depths in the GISP2 Summit ice core. We will study cosmogenic nuclide concentrations in both Pleistocene and Holocene sections of the Summit deep core. The resulting time series of nuclide concentrations will be applied to three main problem areas: dating of ice cores, deducing the history of solar activity and of variations in the geomagnetic field, and studying climatic history through effects of atmospheric circulation and of atmospheric chemistry on nuclide deposition.

Physical Properties

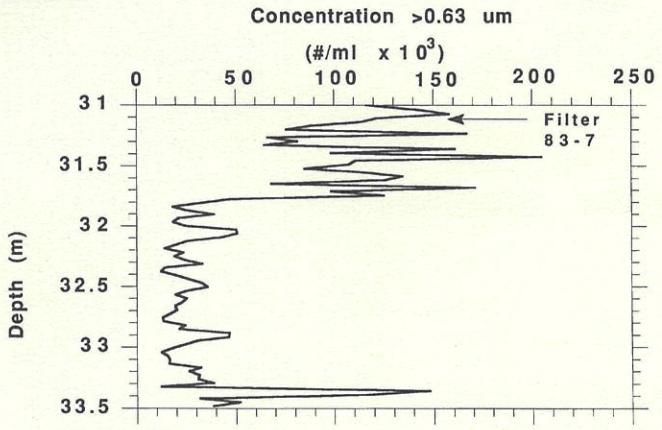


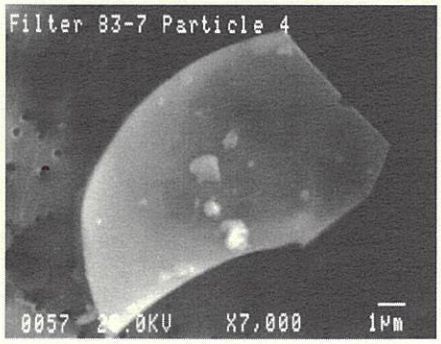
The figure shows the ultrasound velocity profile through the ice in both the longitudinal and horizontal directions. As the crystalline structure becomes aligned the longitudinal velocity increases. Therefore, ultrasonic velocities can be used as a quick first approximation of alignment at depth while the c-axes are being measured to determine exact measurements. CRREL, PSU.



As can be seen in this figure, ice densities increase with depth in the core and start to level off once the firm-ice transition has been reached. CRREL, PSU

Particulates





One type of insoluble particulate matter found in the GISP2 core is volcanic glass. Being able to detect volcanic glass and being able to identify the volcano from which that glass originated is important for, 1) establishing the age of the ice, 2) postulating former circulation patterns, 3) revising the global paleovolcanic record, and 4) evaluating the climatic effects of former volcanic eruptions for comparison with the effects of more recent eruptions like Mt. Pinatubo, Phillipines, in 1991 and El Chichon, Mexico, in 1982.

The figure shown here presents the concentration of insoluble microparticles over a 2.5-meter section of core collected during the 1989 field season. Concentration values in the upper part of this section are frequently over 100,000/ml of H_2O, values that are, by far, the highest observed in any part of the core analyzed to date. Annual layers in the ice and other seasonal signals suggest that this part of the core should date to 1912 A.D. That same year, Katmai, Alaska, erupted producing an extremely large volume of volcanic ash.

To determine if volcanic ash from the Katmai eruption is found in the GISP2 core, we filtered several samples from this 2.5-meter section for analysis by scanning electron microscope (SEM) and electron microprobe. The microphotograph shown here from a depth of 31.1 m (as indicated by the arrow) represents one of the many volcanic shards found in this section of core. The chemical composition of many of these shards, as determined by microprobe analysis, matches that of ash from the Katmai eruption. Thus, volcanic glass from the Katmai eruption is present in the GISP2 core. We are using this same technique to identify ash from other known historical and prehistorical eruptions. UNH.

List of all involved in 1990 or 1991 field season

Carnegie Mellon University
- Jaffrezo, Jean-Luc
- Lin, Tachun

Cold Regions Research & Engineering Laboratory
- Elder, Bruce
- Gow, Anthony
- Meese, Debra

Desert Research Institute
- Borys, Randy
- Keislar, Bob
- Lamorey, Gregg
- Litchfield, Jim
- Mihevc, Todd
- Taylor, Ken
- Wangsgard, Neil

European
- Schoen, Robert
- Marek, Guy
- Silvente, Eric

Lawrence Livermore National Laboratory
- Finkel, Bob

Massachusetts Institute of Technology
- Betts, Joe
- Jayne, Steven
- Sachs, Julian
- Shaw, Tim
- Sherrell, Robert
- Sidor, Inge

Pennsylvania State University
- Alley, Richard
- Cuffey, Kurt
- Jablunovsky, Greg
- Woods, Greg

Polar Ice Coring Office
- Barber, Bill
- Bergman, Karl
- Burton, Tyler
- Cameron, George
- Coates, Rob
- Collins, Jesse
- Curtis, Kevin
- Danford, Bill
- Danford, Julie
- Danielson, Alice
- Dausel, David
- Deboer, Harm
- Eardly, Larry
- Ehlert, Gary
- Gacke, Terrence Leo III
- Giles, Dave
- Goranson, Jim
- Gwynn, Maureen
- Hall, J. J.
- Hancock, Walt
- Hanson, Carlos
- Harrington, Mark
- Kalous, Joe
- Kelley, John
- King, Steven
- Klinck, Jay
- Koci, Bruce
- Koester, Dave
- Kozycki, Larry
- Lamont, Sam
- Larson, Travis
- Lawson, Brian
- Martin, Karyn
- Matulka, Jake
- Melville, Catherine
- Mercer, Cliff
- Miller, Kay
- Peterzen, Steven
- Prescott, Barbara
- Prestridge, Lesia
- Roberts, Doug
- Saulnier, Paul
- Shenton, Ned
- Smith, Pat
- Sonderup, Jay
- Stanford, Kerry
- Stoner, Paul
- Sturges, Sarah
- Walters, Aaron
- Wumkes, Mark

Scripps Institute of Oceanography, UCSD
- Allen, Dave
- Deck, Bruce
- McNulty, Craig
- Weyhenmeyer, Connie

Stanford Research Institute
- Larribeau, John

State University of New York - Buffalo
- Chou, Chiafu
- Frank, Charlotte
- Ellis, John
- Hope, Andrew
- Illing, Matthias
- Kaplan, Michael
- Koenig, Gerson
- Ram, Michael
- Samargian, Victor
- Weber, Peter

University of Arizona
- Wilson, Alex
- Wilson, Bruce

University of Colorado - Boulder
- Barlow, Lisa
- Cannon, Dewitt
- Vaughn, Bruce
- White, Jim

University of Miami
- Connell, Laurie
- Cravens, Eric
- Germain, Claire
- Landreth, John
- Saltzman, Eric
- Sloan, Jim
- Whung, Pai-Yei
- Zetwo, Michelle

University of Michigan
- Clauer, Bob

University of Nevada - Reno
- Lyons, Berry

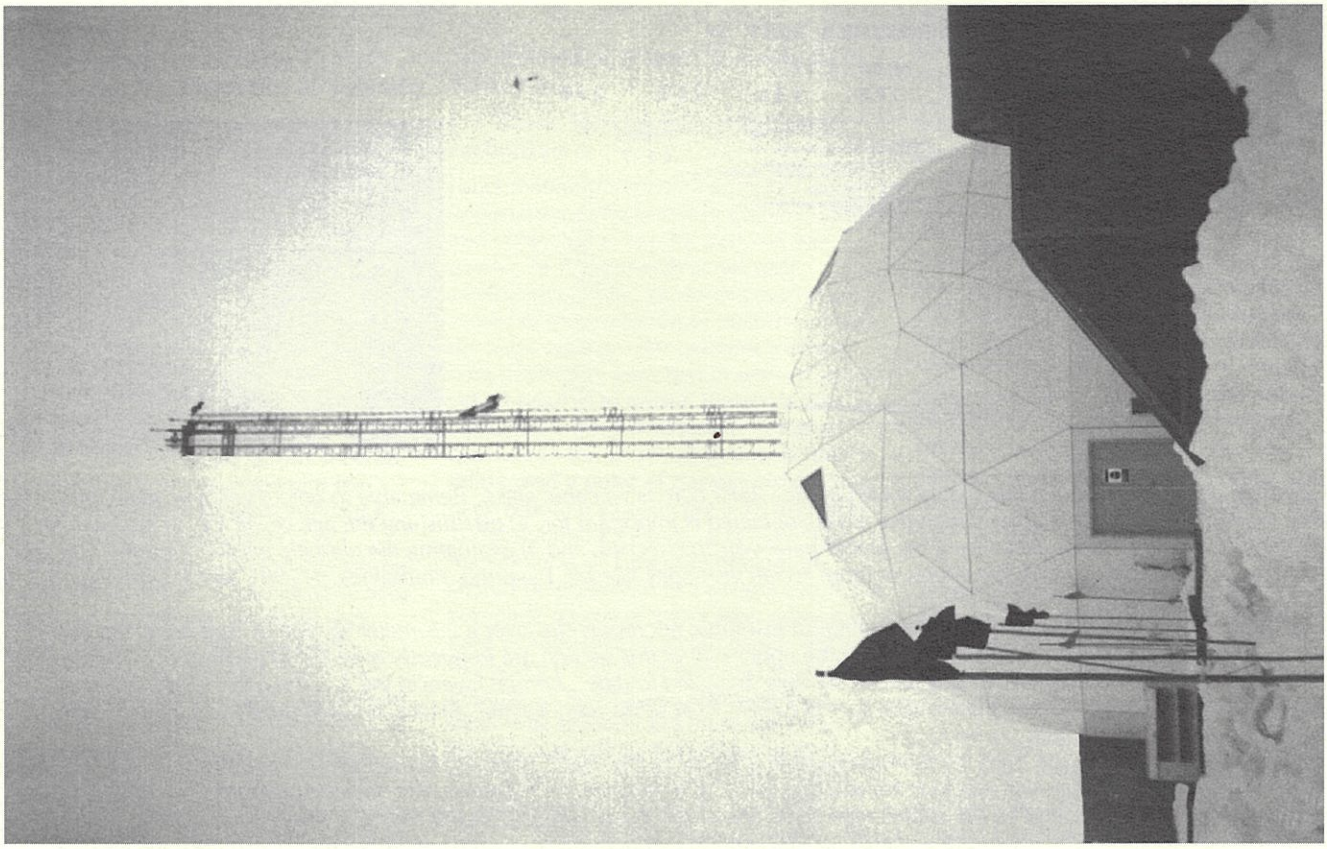
University of New Hampshire
- Barrett, Douglas
- Buck, Chris
- Carpenter, Kevin
- Dibb, Jack
- Drummey, Scott
- Fiacco, Joseph
- Fosberry, Lynne
- Fuller, Bo
- Garrison, Karen
- Holton, Mark
- James, Jim
- Kimball, William
- Kingma, Christopher
- Leamon, John
- Mayewski, Paul
- Mershon, Grant
- Morrison, Michael
- Tatgenhorst, Jim
- Palais, Julie M.
- Pender, Matt
- Putscher, Jennifer
- Tao, Zhou
- Tchao, Amy
- Twickler, Mark
- Welch, Kathleen
- Whitlow, Sallie
- Weyenberg, Scott
- Wood, Jon
- Yang, Qinzhao
- York, Dan
- Zielinski, Greg

University of Rhode Island
- Bender, Michael
- Sowers, Todd

University of Washington
- Duvall, Matt
- Fuchs, Sophie
- Grootes, Pieter
- Massey, Christine
- Paur, Jason
- Saling, Travis
- Steig, Eric

University of Wisconsin - Madison
- Stearns, Charles
- Wiedner, George

USGS - Denver
- Gay, Gene
- Fitzpatrick, Joan



GISP2 Science Management Office
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Durham, NH 03824-3525