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Glaciology of Blue Ice Areas in Antarctica

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Principal Investigator: Hamilton, Gordon S. **Award ID:** 0229245
Organization: University of Maine
Title:
Glaciology of Blue Ice Areas in Antarctica

Project Participants

Senior Personnel

Name: Hamilton, Gordon
Worked for more than 160 Hours: Yes
Contribution to Project:
Gordon Hamilton was responsible for overall project management, planning, and reporting. He participated in field season planning, and was involved in data analyses and interpretation. He was the principal contact between this project and collaborators. Support was provided by this award.

Post-doc

Name: Kurbatov, Andrei
Worked for more than 160 Hours: Yes
Contribution to Project:
Andrei Kurbatov partipitated in field planning and was a member of the Antarctic field team. He was responsible for tephra stratigraphy mapping activities associated with this project, and was also involved in data analyses. Support was provided by this award.

Graduate Student

Name: Spikes, Vandy
Worked for more than 160 Hours: Yes
Contribution to Project:
Blue Spikes conducted the majority of the field planning, data collection, and analyses associated with this project. He served as field team leader for the 1-month Antarctic field season. Support was provided by this award.

Name: Stearns, Leigh
Worked for more than 160 Hours: Yes
Contribution to Project:
Leigh Stearns partipitated in field planning and was a member of the Antarctic field team. She was responsible for satellite image mapping activities associated with this project, and was also involved in data analyses. Support was provided by this award.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Pennsylvania State Univ University Park
Collaboration (joint field season, data analyses, interpretation) with Dr Todd Sowers, PI of a parallel project.

New Mexico Bureau of Mines

Collaboration (joint field season, data analyses, interpretation) with Drs Nelia Dunbar and Bill Macintosh, PIs of a related, parallel project.

University of Lapland Arctic Centre

Collaboration with Dr John Moore, PI of a related Finnish Antarctic Program project examining blue ice regions in Dronning Maud Land. The collaboration included the provision of the University of Lapland radar system and associated software for the duration of the field season. Dr Moore participated in our Antarctic field season, and was involved in data analyses and interpretation.

Other Collaborators or Contacts

We collaborated with Dr Martin Siegert (University of Bristol) and Dr Richard Hindmarsh (British Antarctic Survey) in the refinement of our ice flowline model.

Activities and Findings

Research and Education Activities:

The primary focus of this project is understanding the dynamics of blue ice regions of the Antarctic ice sheet. Two sites in particular were studied. At one site, Mt Moulton in West Antarctica, a 'horizontal ice core' was excavated from a ~250 m long trench in the near-surface a few seasons ago. Potentially, this ice core record extends ~480,000 years. The objective of this project was to investigate the potential for flow-induced disturbance of the stratigraphic sequences. This work was accomplished by field observation and measurement of ice flow, ice thickness, sub-surface layer geometry, and accumulation rate. Field surverys were carried out using precision GPS surveying techniques and high-resolution radar profiling. A second site at the Allan Hills in East Antarctica was investigated for its potential to yield a horizontal ice core record extending >1 million years. Earlier field studies were used to formulate an ice flow model that was subsequently evaluated and re-tuned using additional field data of ice flow, ice thickness and accumulation rate.

Findings:

Analyses to date of field data collected at Mt Moulton indicates that ice-flow induced disturbance of stratigraphic sequences is not a major problem in this blue ice region. Flow velocities, as expected, as very slow (<1 m/yr) and strain rates are small. Radar profiling of internal stratigraphy reveals conformal layer geometry and the absence of folding or other flow-induced patterns. There is some indication, however, that sections of the 480,000 year record are missing, perhaps as a result of extended periods of surface ablation or ice flow over shallow bedrock obstacles. We are in the process of reconstructing the flow history for this site and identifying sections where the stratigraphic record might be unreliable.

Field data collected at the Allan Hills were used to improve an existing ice flow model for this region. The model predicts stratigraphic ages for layers exposed at the surface. In some places, ice in excess of 1 million year old is identified. We are in the processing of exploring the validation of these results used terrestrially-age-dated meteorites.

Training and Development:

The field component of this project was conducted by two graduate students and a postdoc. These students gained experience in project planning, experimental design, field logistic operations, and field team management. All field team members were able to develop skills in GPS satellite surveying, radar profiling, and numerical ice flow modeling. All project members were involved in data analysis and interpretation.

Outreach Activities:

One of the students involved in the project, Leigh Stearns, was an NSF K-12 Science Teaching fellow in the academic year following the field season. She incorporated material from this project into her high school science classes. Project personnel made several additional visits to local area elementary school, before and after the field season. During the field expedition, team members maintained an online diary and answered questions from school children. The diary was linked through our institute's website (http://climatechange.umaine.edu/Research/Expeditions/2004/blueice.html).

Journal Publications

Grinsted A., J. Moore, V. B. Spikes, A. Sinisalo,, "Dating Antarctic blue ice areas using a novel ice flow model", Geophysical Research Letters, doi:10.1029/2003GL017957, p. 2005, vol. 30, (2003). Published

Books or Other One-time Publications

Web/Internet Site

URL(s):
(1) http://climatechange.umaine.edu/Research/Expeditions/2004/blueice.html
(2) http://gcmd.nasa.gov/getdif.htm?Hamilton_0229245

Description:
(1) This site describes the project and contains the diary entries uploaded during the Antarctic field season.

(2) This site is the metadata entry for this project.

Other Specific Products

Contributions

Contributions within Discipline:

This project represents one of the most detailed studies of flow dynamics in Antarctic blue ice fields yet undertaken. Together with results from the companion UMaine/NMBM/Penn State project, a very detailed view of one ice field in particular, Mt Moulton, is emerging. Blue ice regions are increasingly recognized for their climatic and paleoclimatic significance (changes in extent as an indicator of the former, and as accessible long-term archives useful for studying the latter). The results of this study are contributing to our glaciological knowledge of how these features flow, how they preserve stratigraphy, and their long-term signficance.

Contributions to Other Disciplines:

This project contributed to the study of glaciologically-related discplines, most notably Antarctic paleoclimate. The principal contribution was a glaciological assessment of the longevity and preservation of stratigraphic sequences in Antarctic blue ice fields. The field component also contributed to radar geophysics, through the study of internal ice sheet reflectors and their electromagnetic causes.

Contributions to Human Resource Development:

This project provided an in-depth opportunity for young researchers (doctoral graduate students) to develop skills in scientific project management, team leading, and field experimentation. There were also opportunities for developing new technical skills (e.g., radar data processing, tephra mapping).

Contributions to Resources for Research and Education:

As part of this project, the Glacier Dynamics Group at UMaine updated its capability for processing radar geophysical data. The project also provided a venue for developing an international collaboration between UMaine and the University of Lapland, as well as modeling colleagues in the UK, and the sharing of technical resources.

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Any Book

Any Product

Contributions: To Any Beyond Science and Engineering

Introduction

In this project, we collected field information on ice velocity (using GPS), ice thickness and stratigraphy (using radar), and firn density (from cores) at blue ice sites at Mt Moulton and the Allan Hills (Figure 1). These data, and associated numerical modeling, provide the insights into the age and preservation of stratigraphic sequences at both locations which are necessary to interpret available and potential 'horizontal' ice core records.

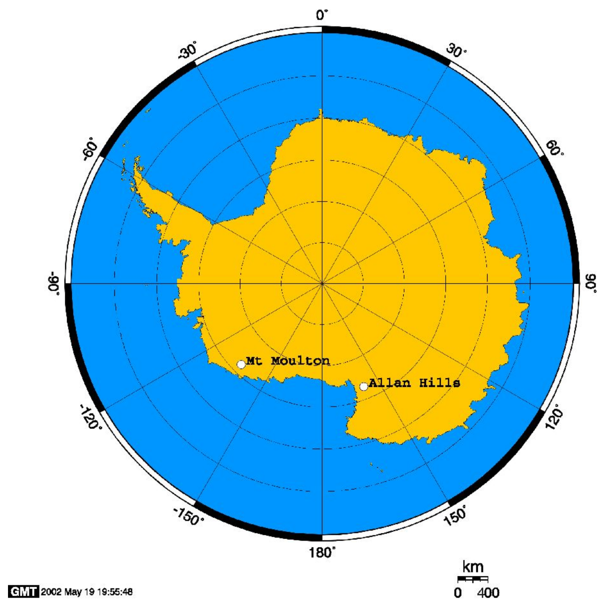

Figure 1. Location of the two studied blue ice fields.

Mount Moulton

The blue ice field is located on the upflow side of Prahl Crag. Ice drains from the summit of Mt Moulton, flows towards the crag where progress is impeded, and the layers outcrop at the surface as a result of emergent ice flow. Kinematic GPS surveys show that the blue ice field has a steeper slope than the surrounding firn fields (Figure 2). At issue is whether or not the stratigraphy is continuous in the blue ice field. Potential complex subglacial topography and the crags might have caused layers to be stripped from the record by ice flow processes. If layers are indeed missing, it makes problematic the interpretation of the horizontal ice core record.

We performed radar surveys with the aim of mapping internal stratigraphy and basal topography. Unfortunately, neither technique was especially successful. The deep

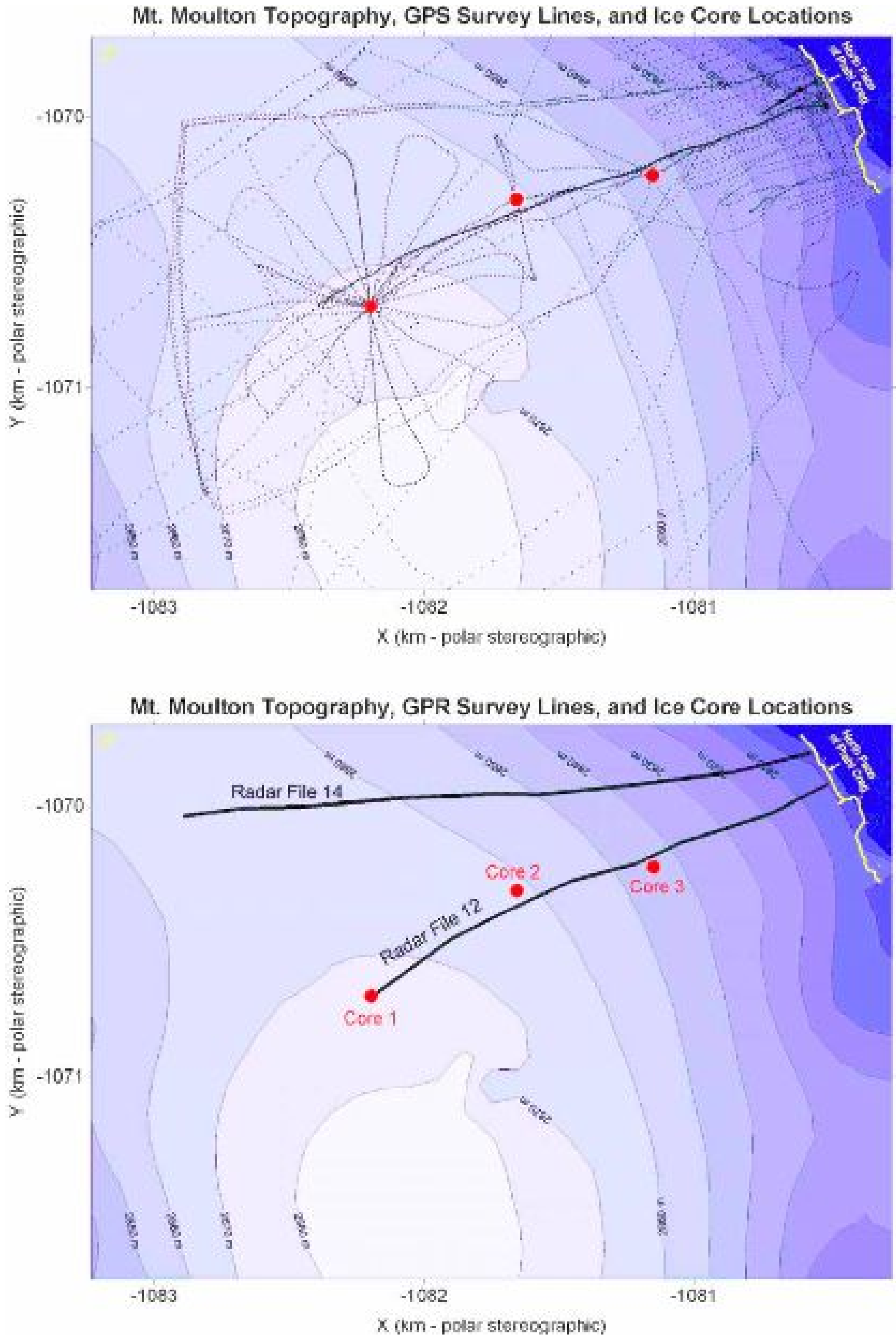

Figure 2. Surface topography as measured by kinematic GPS, and location of radar profiles, firn cores, and ice core trench.

radar (a 10 MHz system on loan from Dr J. Moore, University of Lapland) did not function in the field, probably as a result of transit problems. The shallow radar (a 400 MHz ground penetrating radar provided by Dr S. Arcone, US Army CRREL) was operated successfully, but the data were not as useful as expected. Clear stratigraphic layering is observed in the firn regions (Figure 3a), but practically no stratigraphy is visible in the blue ice areas (Figure 3b). We hypothesize that the dip angles of layers in this region are too steep to be tracked by radar operating at the frequency and stacking rate used in the field.

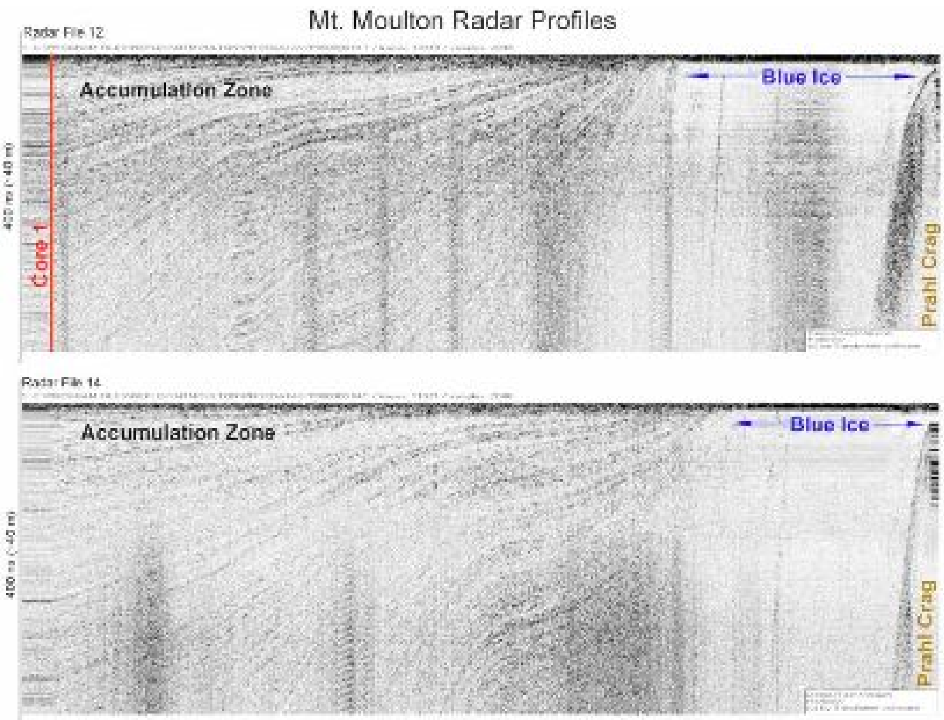

Figure 3a. 400 Mhz radar profiles in the firn region above the Moulton blue ice field. See Figure 2 for profile locations.

The lack of good radar data makes it difficult to evaluate the potential for discontinuous stratigraphy along the trench section. To better understand this potential, we collaborated with Dr J. Moore and and his PhD student Aslak Grinsted (University of Lapland) in the development of a model which calculates ages based on measured chemistry profiles obtained from analysis of the trenched material. Ice flow measurements (Figure 4) are used as validation. The key to the model is that it calculates the effective smoothing length in the chemistry profiles caused by the fixed chemical sampling interval. The method resolves the smoothing needed to match a 40 point window of chemistry data with a reference section selected from 150-200 m along the trench. Smoothing distances are then converted to mean layer thicknesses for constructing the age–depth scale. Preliminary results of this approach are instructive, but we caution that the model needs additional refinements.

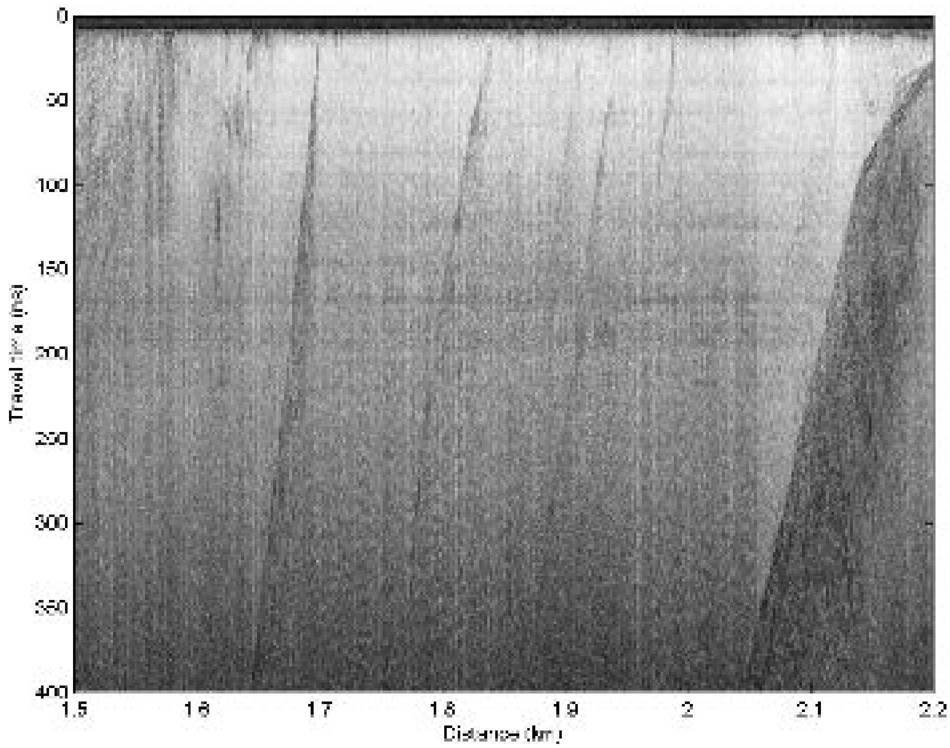

Figure 3b. 400 MHz radar profile across the blue ice field. Note the lack of well-defined stratigraphy.

The modeled age–depth scale is compared against the existing age–depth scale derived from dated tephra layers (Figure 5). We fix the timescale using tephra dates of 9.5 kyr and 106.3 kyr for a 200.5 m long section. Both age–depth scales are in close agreement, except for the section close to 125 m. One interpretation is that the 27 kyr tephra data is in error, perhaps because of an uncertainty in where the tephra material was recovered relative to the trench location. If we assume this is a valid explanation for the mismatch between the two age–depth scales, and further assume that the modeled scale is correct, we can re-scale the layer thicknesses to this new timeline. Such an exercise reveals interesting results (Figure 6). For the purposes of comparison, we compare

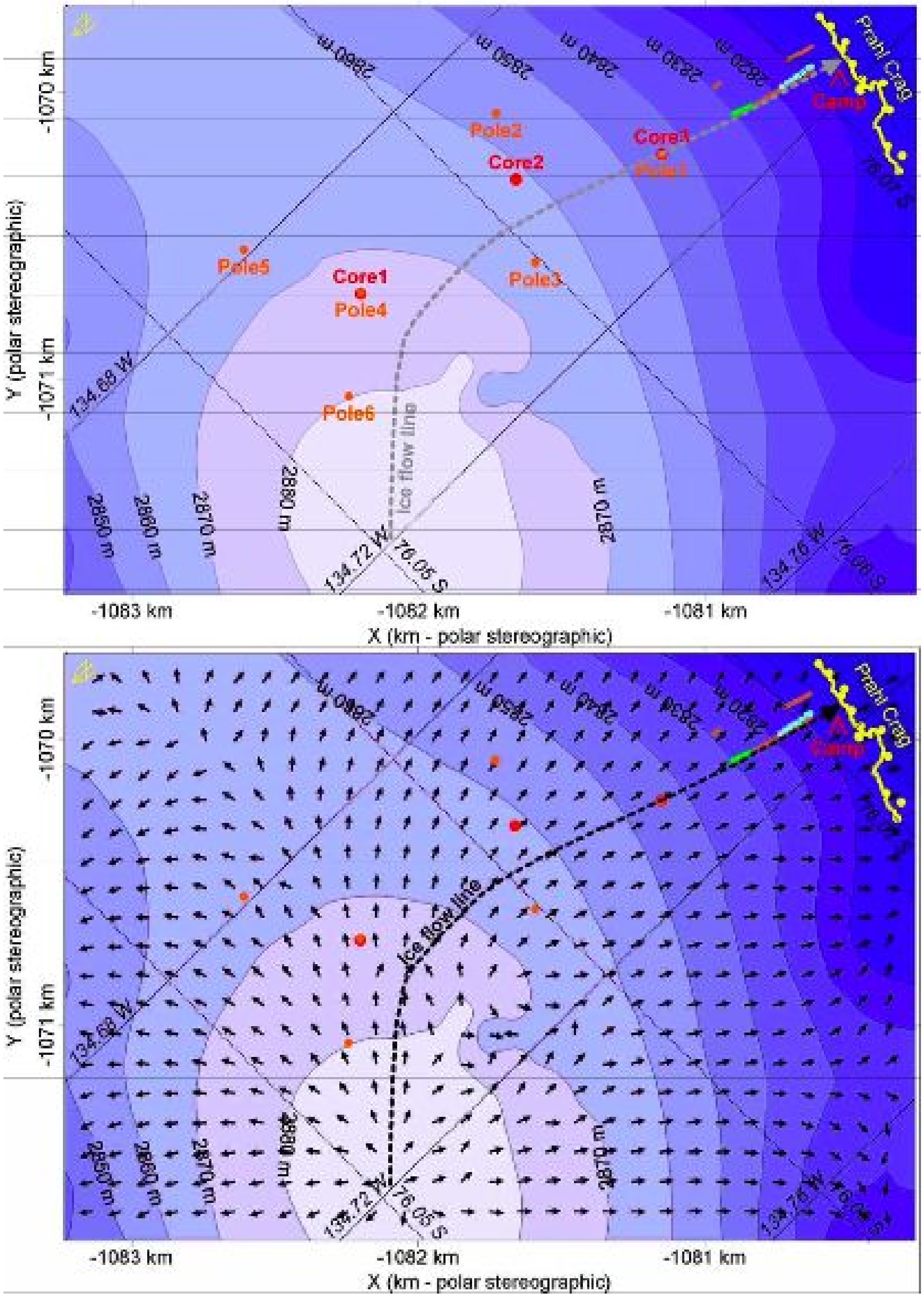

Figure 4. Modeled ice flow field and location of field GPS measurements used to constrain model.

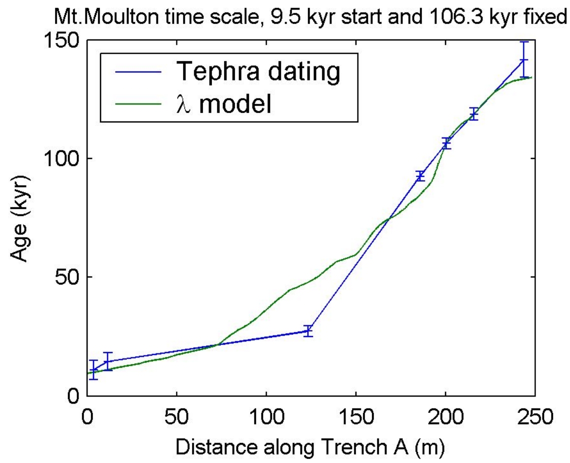

Figure 5. Timescale from the layer thickness estimates (green) obtained by fixing the curve with a starting age of 9.5 kyr at 0 distance, and an age of 106.3 kyr at 200.5 m, compared with tephra ages, and 2 sigma error bars (blue).

Moulton layer thicknesses with EPICA Dome C deuterium excess and sulfate, and NGRIP isotopes. Note the good anti-phase relationship between Moulton layer thicknesses and NGRIP isotopes at circa 22 kyr. There is a second step in Moulton layer thicknesses which coincides with the increase in EPICA deuterium excess. The Antarctic Cold Reversal at circa 14 kyr is evident in Moulton record, which leads us to argue that our reconstruction is valid.

The warming events seen in the EPICA and NGRIP records are observed also in the Moulton record, with the exception of the initial warming at 22 kyr. This rapid increase in accumulation rate coincides with a tantalizing step-up in the NGRIP isotope record, leading us to conclude that the Moulton event is real. There are several plausible reasons why Moulton would see a different signature than central Antarctica, perhaps because of its proximity to the ocean and possible changes in sea ice extent and coastal circulation patterns. Our results are tentative and the subject of ongoing study.

Allan Hills

The most accessible region of exposed ancient ice in Antarctica is located just west of the Allan Hills nunatak. The Allan Hills blue ice region is actually composed of four distinct ice fields: the Main Ice Field (MIF), Near Western Ice Field (NWIF), Mid Western Ice Field (MWIF) and Far Western Ice Field (FWIF). The FWIF is geographically distinct from the other ice fields (it is ~50 km from the MWIF) and we did not study it as part of this project.

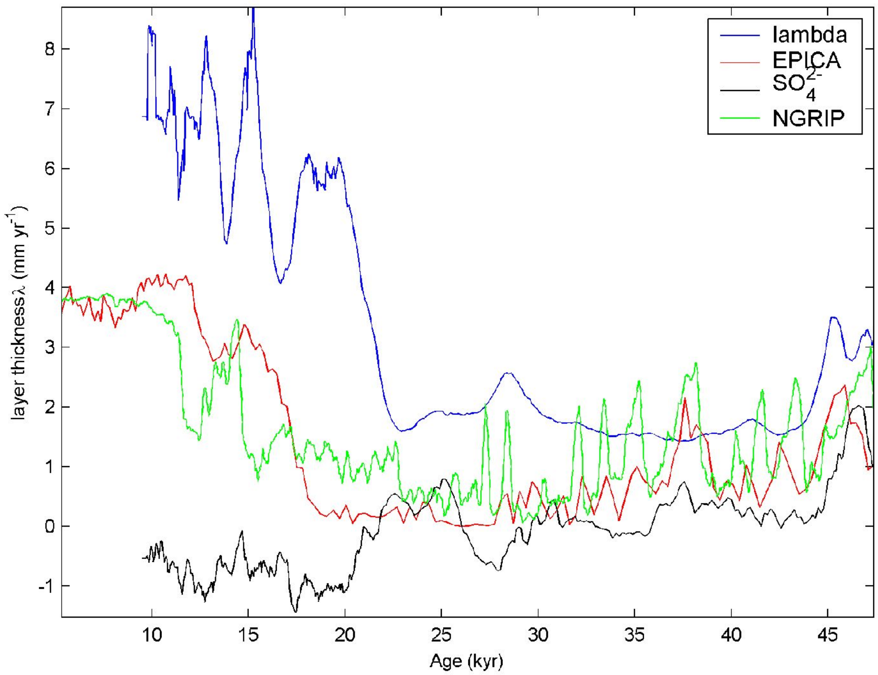

Figure 6. Comparison of Moulton layer thicknesses derived from the modeled age – depth scale ("lamba" thicknesses) against EPICA deuterium excess and sulfates, and NGRIP isotopes. Only the portion of the record close to the termination is shown here. Note the rise in accumulation rate (layer thickness shown by the blue line) at approximately 22 kyr in the Moulton record.

As with at Mt Moulton site, the radar profiling did not yield the quality of data we expected. Stratigraphy is traceable in firn areas, but not in the blue ice fields. Again, we hypothesize that the radar frequency and stacking rate were not optimized for steeply dipping layers.

We resurveyed a network of markers installed during an earlier project to derive long-term (~ 4 years) ice velocities. Flow speeds are extremely slow (< 0.6 m/yr) at all locations, but are faster on the Main Ice Field than on the Near Western Ice Field or Mid Western Ice Field (Figure 7).

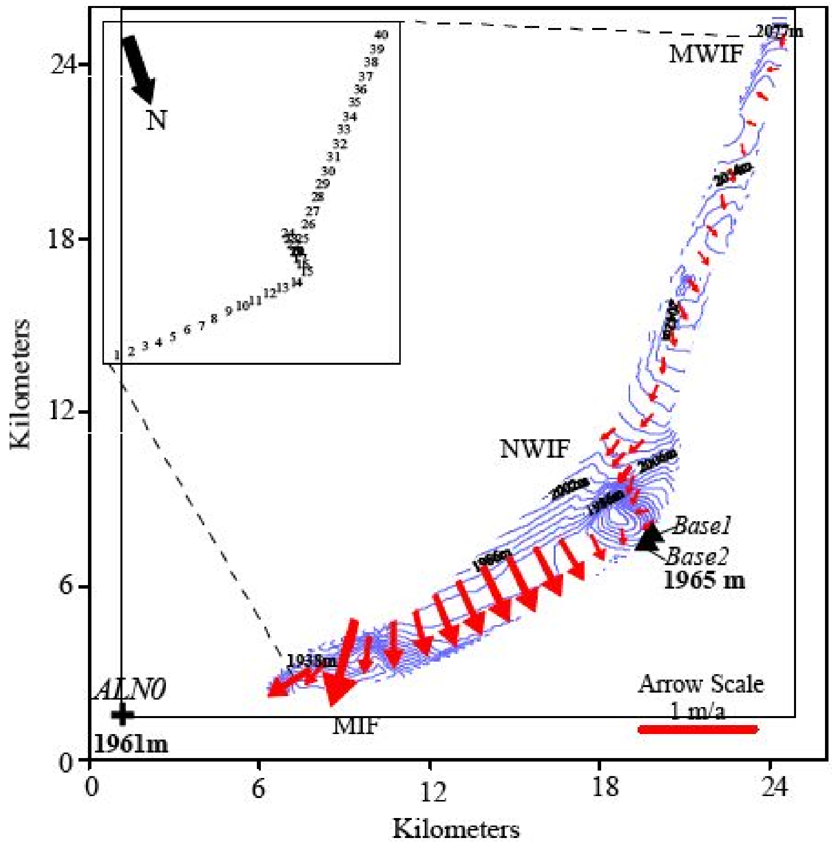

Figure 7. Ice flow velocity vectors as determined by repeat precision GPS surveys. The marker poles are located in the center of each arrow. Contour interval is 4 m with a vertical resolution of 25 cm or better. Contouring includes only the area covered during kinematic GPS surveys.

The velocity data and measured accumulation rates derived from shallow cores were used to constrain an improved ice flow model for the region. Applied to the NWIF, the model indicates outcropping ice at the surface reaches an age of 130,000±20,000 years at the extreme downglacier end (Figure 8). This age is consistent with previously reported terrestrial ages of meteorites recovered in this region, and implies that the model is valid. With this confidence in hand, the model applied to other parts of the Allan Hills indicates the presence of extremely old ice (1.5-2.0 Ma) on the MIF. These results are useful for planning future ‘horizontal’ ice coring activities, for such purposes as collecting large volumes of ice from important climate periods (e.g., the Eemian) or sampling climate transitions in the deep past for which other records are rare.

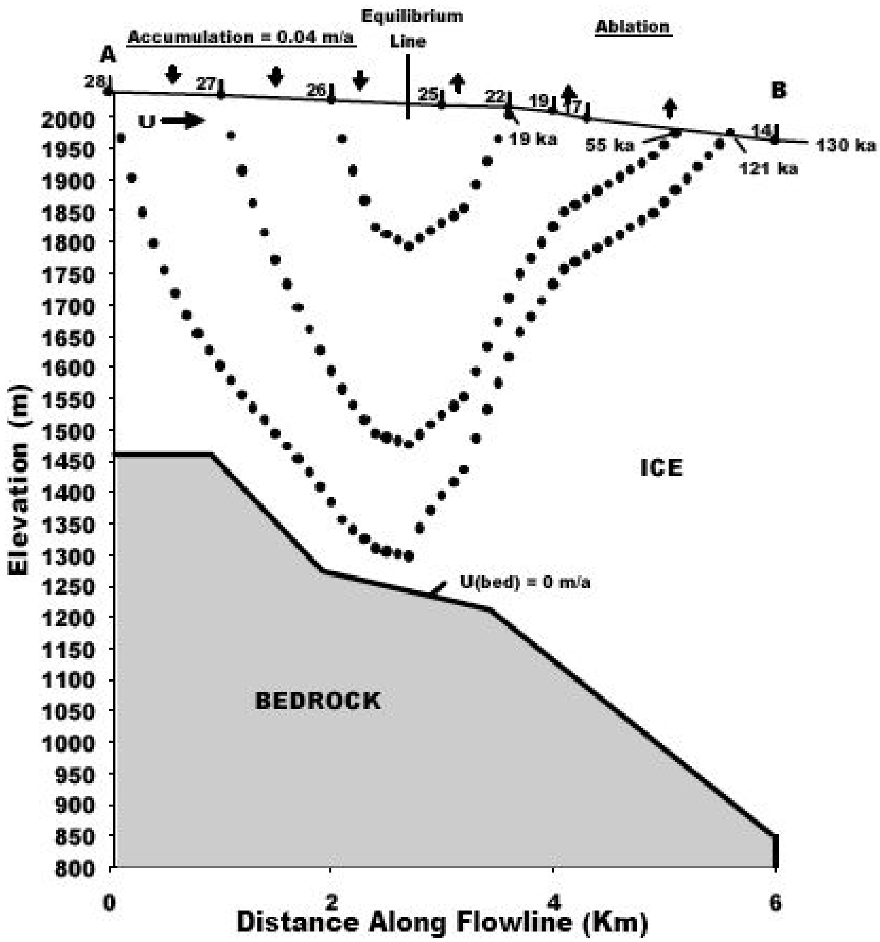

Figure 8. Steady-state ice flow trajectories for ice at the NWIF using field data. Each dot represents 100m of horizontal movement. Accumulation rate used in this model run is the average accumulation rate for the snow plain between the NWIF and MWIF.