Interpretation and Uncertainty of Byrd ice core data and airborne radar sounding observations

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1. Abstract [200 words]

Data from radar-sounding surveys of West Antarctica are used to determine the age of observed radar horizons near the Byrd ice core, Antarctica [Gow, 1968]. We emphasize inclusion of uncertainty in radar- and ice-related sources of uncertainty. We present a new chronology of the Byrd ice core which takes into account theoretical and measurement uncertainties in depth and age of prominent layers observed in the ice.

2. Introduction [4 pages double spaced]

The West Antarctic Ice Sheet (WAIS) has become an important focus of glaciological research because it is the last marine ice sheet on Earth. A full 75% of the ice sheet is based below sea level, leaving the region susceptible to the Marine Ice Sheet Instability Problem. [source] This problem is characterized by the unique bedrock topography of West Antarctica, in which the bedrock slopes down toward the interior of the continent. As the ice sheet retreats due to melting or calving at the front, the grounding line moves back to a thicker part of the ice sheet. In the absence of longitudinal forces or a buttressing ice shelf to hold back the ice sheet, discharge will increase, leading to further retreat. This process acts as a positive feedback to the system, resulting in accelerated retreat of the grounding line until the ice sheet reaches a steady state position upstream.

Marine ice sheet instability could therefore be responsible for a rapid disintegration of up to 75% of the West Antarctic ice sheet. This scenario would result in a global sea level rise approaching 5 m. [source] Such a severe rise in sea level would threaten tens of millions of individuals worldwide living in Low Elevation Coastal Regions. [source?] It is therefore important to gain a better understanding of ice flow in West Antarctica in order to gauge its stability in response to climate change.

Isochronous layers within glaciers provide one avenue for developing an understanding of ice dynamics. Each winter, snow is deposited onto the surface of a glacier. This snow contains signatures of atmospheric conditions and other isotopic clues about climatic conditions at the time of deposition. [source] Over time, each layer is covered with the accumulation of subsequent years, where it is compacted first into a layer of firn and then into ice as it becomes buried in the ice column. This process produced isochronous layering within the glacier that carries a signature of the surface conditions at the time of snowfall.

One such signature is the accumulation rate. The thickness of an isochronous layer represents the accumulation over the period of deposition of that layer. As the layer is advecting down into the glacier, it will thin as a result of gravitational compaction, but it is possible to correct for this effect and so retain some information about accumulation rate is the period of deposition can be discerned. Accumulation rates and patterns of accumulation are related to several climatic factors of interest including air temperature and surface topography. [source] This makes it possible to begin recreating ancient climates from long-buried layers of ice.

It is also possible to learn about ice flow from drawdown and deformation observed in the layers. Layer draw down, in which layers move deeper in the glacier (with or without a corresponding change in bed topography) may be indicative of basal melting. [e.g. source] In some cases, observation reveal layers disappearing from the bottom of the ice sheet, a sign that ice is melting from the base. This could correspond to areas of fast-moving ice (past or present) such as an ice stream, or may indicate an area of increased geothermal heating.

In addition to their usefulness for understanding ice dynamics, these isochronous ice layers provide a glimpse into the interior of a glacier where other observational methods are rendered useless. Ice-penetrating radar surveys of ice sheets reveal internal layers as radar reflection horizons. These horizons can be tracked over large glacial regions, in some cases tracing ice flow across hundreds of kilometers, as in the case of West Antarctica. [source] As mentioned earlier, this allows for studies of paleoclimate over large regions of an ice sheet. In East Antarctica, it presents scientists with the opportunity to compare ice core analyses between stations located throughout the region. [source] This cross-correlation provides an unprecedented opportunity for uncertainty quantification of ice core chronologies.

Because internal layering encodes information about accumulation rates and deformation as ice flows, they can be used to develop a picture of ice dynamics. One of the main obstacles in ice sheet modeling is the uncertainty surrounding basal boundary conditions. One way to explore this problem is to use surface observations to invert for basal parameters. [source] Dynamical information about the flow of ice within the column, derived from analyses of internal isochrones can further inform these inversion problems to more accurately describe and reduce uncertainties in basal boundary conditions.

Some of the latest technology in aerogeophysical surveys of Earths major ice sheets includes focused synthetic aperture radar (SAR) techniques. Focused radar products provide an even better picture of glacial isochrones by including additional clutter reduction and preserving echoes from sloped layers. This enhances our ability to detect and track layers, even in more complex englacial environments. [source Peters paper]

[More about the wonders of radar]

3. Statement of the problem [3 pages]

With recent improvements in the processing of airborne radar sounding observations, detection of internal layers has become increasingly reliable and informative. Airborne radar surveys are being used to study a wide range of glacial properties and processes such as glacial hydrology, ice dynamics, and mass balance. Despite the advancement in these observational techniques, however, there has been no comprehensive quantification of the uncertainties associated with airborne radio echo sounding. In some cases, such as near the base of the ice sheet where opportunities for observations are limited, large uncertainties can be expected.

As with all data collection, it is important to recognize the limitations of observational techniques. One way in which to do this quantitatively is to do a thorough uncertainty analysis. This can provide a more true picture of how much data can be trusted to present an accurate picture of the physical state of a glacier. A comprehensive review of uncertainties also offers an opportunity for uncertainty reduction through refinement of observational techniques by quantifying the contribution to uncertainty made by each aspect of the observational method.

In addition to encouraging improved approaches to data collection, uncertainty quantification is key to interpreting scientific results. In the case of internal radar reflection horizons and ice dynamics, there is uncertainty attributed to the determination of the horizon depths as well as the ages assigned to those depths. The next two section describe in more detail what the sources of uncertainty are in each of these cases.

3.1. Uncertainty in Two Way Travel Time(TWTT)

There is uncertainty in the picked depth of radar layers. GeoFrame, seismic interpretation software, allows a user to select strong reflectors from a radargram and trace them along a radar line. However, there is a fundamental limit to how accurate the depth of these layers be given the resolution of the sampling rate of the radar transmitter. This sampling rate reflects the fact that the radar operates by emitting electromagnetic pulses. The receiver then samples the reflections at a given rate. The sampling rate for the data used in this study varies from 5 ns to 20 ns and so we assume a resolution of 10 ns when picking the reflections from the surface of the ice sheet and from each internal layer. We treat the surface and internal layers separately in this instance.

To convert TWTT uncertainty into units of depth, we scale the time by the velocity of electromagnetic wave propagation. For example, we assume the pulse travelled to the surface with velocity, c, the speed of light, but then slowed to the velocity of electromagnetic wave propagation in ice, which we assume to be 1.69 x 108 m/s before reaching the internal layers. The corresponding $1/sigma$ uncertainty is 0.3 m for the surface reflector and 0.17 m for the internal layers.

The finite bandwidth of the data means that even an infinitesimally thin layer of ice will appear in the survey to have a finite width. Our data used a pulse bandwidth of 15 MHz. This translates to a 1σ depth uncertainty of 5.63 m, obtained from considering both the bandwidth frequency and the velocity of electromagnetic radiation in ice. This uncertainty is applied as a random, normally-distributed error in the depth of each of our selected layers.

3.2. Uncertainty in Byrd ice core chronology

4. Research Plan [3 pages]

5. References

References

Gow, A. J. 1968, 1