Histories of Accumulation and Ice Dynamics from Radar Layers and Ice-Flow Inverse Methods

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- INTRODUCTION -

Depth-age relationships from ice cores contain a record of past accumulation and ice-sheet dynamics. Profiles of radar-detected internal layers (assumed to be isochrones) add the spatial dimension to temporally resolved records from ice cores. The deeper, older layers record conditions from further in the past, but they have also been subjected to larger horizontal gradients in strain and accumulation, making them more difficult to interpret than near-surface layers. As the depth to the layer increases to a larger fraction of the total ice thickness, accumulation rates based on depth variations alone or corrected using a 1-D flow model are no longer appropriate. We use a flow-band model to calculate ice-surface and layer evolution and to predict internal layer positions and shapes. Solving this forward calculation requires information about spatial and temporal variations of accumulation rate and ice sheet dynamics, which are not known.

Inverse methods are used to find physically reasonable values for the unknown parameters that generate internal layers that fit the data within a defined tolerance. This procedure assimilates radar data to extract a spatially and temporally variable accumulation history as well as information about ice divide migration and ice thickness evolution.

Forward Problem:

model parameters → model → predictions of data

Inverse Problem:

data → model → estimates of model parameters

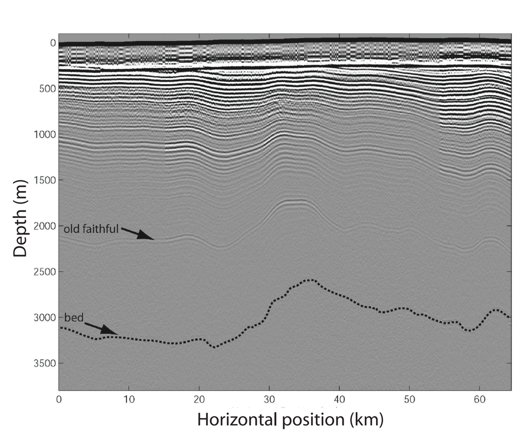
Using inverse theory allows us to gain information about the unknown model parameters (e.g. accumulation rate).

(Menke, 1989; Parker, 1994; Aster and others, 2005)

- DATA -

The primary sources of data are internal layers imaged by ice-penetrating radar. The model needs an estimate of the ice-sheet geometry including surface topography, bed topography, and flowband width. We can incorporate any additional data available. For example, layer age, accumulation rate measurements, and ice velocity measurements.

Internal layers at the WAIS divide site can be traced back to ~18,000 years.



Example radar profile near upcoming WAIS divide ice-core site.

- METHODS -

Transient Ice Flow Model (FORWARD MODEL)

Description

- Shallow Ice Model
- 2.5-D Flowband geometry
- Limited ice-sheet domain
- Control-volume numerical scheme
- Solves coupled transient advective-diffusion
- Temperature-dependent softness parameter
- Particle-tracking

Input

- Initial surface topography
- Bed geometry
- Flowband width
- Initial temperature distribution
- Input ice flux
- Geothermal flux
- Accumulation rate

Output

Particle paths
--> map out internal layers

Gradient Method (INVERSE MODEL)

Description

- Minimizes performance index based on trade-off between:
  1. Model Smoothness (spatially smooth accumulation)
  2. Data misfit (differences between data layers and predicted layers from forward model)

Model Parameters

- Accumulation rate
- Input ice flux
- Layer age
- Geothermal flux
- Softness parameter

Data

- Internal layers
- Present-day surface

if available:
- Ice velocity
- Layer ages
- Present-day accumulation

Output

Adjustments to the model parameters to better minimize the performance index

Iterative Solution Scheme

Step 1

- Assign a value of the trade-off parameter
- Run forward model
- Generate internal layer based on inital values

→

Step 2

- Calculate:
  Model smoothness
  Data misfit
- Find adjustments to model parameters (accumulation rate)

→ **Rerun Forward Model**

Keep the same value of the trade-off parameter and rerun the forward model with adjusted parameter values.

→ **Convergence**

Performance index is minimized. Reasonable solution is found.

Choose Final Solution

The final solution is associated with a trade-off parameter that has a data misfit equal to the tolerance.

- APPLICATION to the WAIS -

The upcoming WAIS Divide ice core will provide a high resolution climate record for the past ~100,000 years. Our model domain will extend through this new drill site and can be tied into the Byrd core.

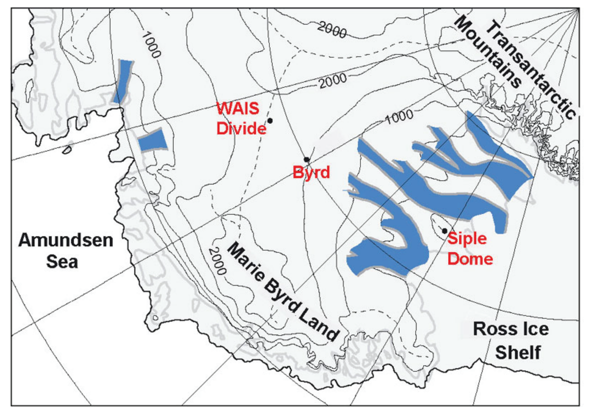


Image from http://waisdivide.unh.edu

Spatial and Temporal Accumulation

We will use ice-penetrating radar data to add the spatial dimension to the temporal record from the ice core.

Ice-Thickness History

We will explore the longer-term history of the WAIS, including thickness changes since the most recent deglaciation. Conflicting views on the WAIS configuration have different implications for global sea level.

Ice-Divide Migration

We will get the divide history of the Ross-Amundsen ice divide. It is unclear to what extent the divide has migrated, and to what extent migration could have interacted with the regional accumulation gradient.

Geothermal Flux

A by-product of our inversion is the spatial pattern of geothermal flux. The degree to which basal melting has affected the ice in this area is largely unconstrained.

- IN the FUTURE -

Completion of transient forward model, incorporating transient temperature model (from S. Price).

Investigate resolving power of defined model parameters in our inversion.

Begin application to WAIS ice core site.

- References -

Aster, R. and others (2005). *Parameter Estimation and Inverse Problems.* Elsevier Academic Press.
Menke, W. (1989). *Geophysical data analysis: discrete inverse theory*. Academic Press.
Parker, R. L. (1994). *Geophysical Inverse Theory.* Princeton University Press.
Waddington, E.D. and others (In Review). *J. Glaciology*.