Transient Modeling of Borehole Temperature and Basal Melting in an Ice Sheet

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Prix de Quervain 2016

25th of November 2016

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Goals

Develop an ice age model in Antarctica.

Use the model to find a site in Antarctica which would be ideal to find 1.5 Myr old ice.

http://earthobservatory.nasa.gov
Past environmental conditions and direct information on atmospheric composition.

Recover an 1.5 Myr old ice core would allow us:

- To extend our knowledge of past climate
- To understand ice sheet dynamics and anticipate climate changes
Dome Concordia Station

Oldest ice core existing: 800’000 yr

www.asoc.org
Oldest ice - Requirements

- Old ice retrieval 1
- Model details
- Tests
- Corrections
- Old ice retrieval 2
Model development

Requirements (physical-mathematical):

• Describe the snow and ice density
• Describe mechanical properties (ice compaction)
• Describe the heat diffusion
• Describe the basal melting
• Compute the age of the ice

\[
\frac{\partial T(z, t)}{\partial t} = \frac{K(z, t)}{\rho(z, t)c(z, t)} \frac{\partial^2 T(z, t)}{\partial z^2} - w(z, t) \frac{\partial T(z, t)}{\partial z} \\
+ \frac{1}{\rho(z, t)c(z, t)} \frac{\partial K(z, t)}{\partial z} \frac{\partial T(z, t)}{\partial z} + \frac{\dot{E}_I(z, t)}{\rho(z, t)c(z, t)}
\]

→ Develop a program solving all the equations
Boundary conditions

Boundary conditions:
- Surface temperature
- Accumulation rate
- Ice thickness
- Ground heat flux

From today to 800’000 yr before present:
- Dome C time series

From 800’000 yr to 4Myr before present:
- Lisiecki and Raymo, 2005 δ^{18}O parameterization
Boundary conditions

- Old ice retrieval 1
- Model details
- Tests
- Corrections
- Old ice retrieval 2

LR04EDC Temperature

LR04EDC Accumulation rate

LR04EDC Thickness

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Model output

- Old ice retrieval 1
- Model details
- Tests
- Corrections
- Old ice retrieval 2

**Temperature last 1 Myr**

- 1e+06
- 9e+05
- 8e+05
- 7e+05
- 6e+05
- 5e+05
- 4e+05
- 3e+05
- 2e+05
- 1e+05
- 0

- 0
- 200
- 400
- 600
- 800
- 1000
- 1200
- 1400
- 1600
- 1800
- 2000
- 2200
- 2400
- 2600
- 2800
- 3000
- 3200

- Temperature (°C)
- -60
- -50
- -40
- -30
- -20
- -10

- Time B.P (yr)
- Height (m)

- -10°C
- -20°C
- -30°C
- -40°C
- -50°C
Model output

- Old ice retrieval 1
- Model details
- Tests
- Corrections
- Old ice retrieval 2
Tests of the model

Greenland

- Old ice retrieval 1
- Model details
- Tests
- Corrections
- Old ice retrieval 2
Tests of the model

Antarctica

Temperature

- Borehole measured temperature
- m=0.4 QG=54
- m=0.5 QG=56
- m=0.6 QG=58

Age

- C. Ritz age scale
- m=0.4 QG=54
- m=0.5 QG=56
- m=0.6 QG=58
Correction of the model

Topography

Valley ~100 m deep and ~5000 m wide at Dome C (Forieri et al., 2005)

Can warm the profile up to ~0.2°C → Not enough but shows the importance of topography

Boundary conditions (temperature and accumulation) correction
Tests of the model

Antarctica

Temperature

- Borehole temperature
- T+2°C and A+5%

Age

- C. Ritz age scale
- T+2°C and A+5%
Where will we find old ice?

If the climatological conditions are the same than at Dome C, we expect to find older ice where the ice sheet is thinner.

Because more ice $\rightarrow$ more pressure $\rightarrow$ more melting

But too thin ice $\rightarrow$ too thin annual layers

$\rightarrow$ We run the model with different ice sheet thicknesses
Oldest ice site

- Old ice retrieval 1
- Model details
- Tests
- Corrections
- Old ice retrieval 2
Oldest ice site

Age 25 m a. bedrock

Today's ice thickness (m)

Old ice retrieval 1
Model details
Tests
Corrections
Old ice retrieval 2
Oldest ice site

- Old ice retrieval 1
- Model details
- Tests
- Corrections
- Old ice retrieval 2

**Age 25 m a. bedrock**

![Graph showing the relationship between age before present (B.P.) and today's ice thickness (m). The graph compares older simple models and new model predictions.](image)

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Summary

Model in agreement with literature and measurements in Greenl.

Model not able to reproduce temperature measured at Dome C

Corrections needed in boundary condition

1.5 Myr old ice very likely exists at 25 meters above bedrock

Ideal ice thickness is between 2750 and 2900 meters

Transient model is an improvement with respect to steady state model
Thank you for your attention