EISMINT Phase II
Comparison of existing Antarctic models

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1. Introduction

The objective is to compare existing models of the Antarctic ice sheet, and to find out how they perform under prescribed climatic and environmental forcings. Compared to the other intercomparison tests (grounding-lines, ice shelves and Greenland), the important new feature is the evaluation of treatments for grounding-line migration in the two horizontal dimensions.

The experiments aim at comparing steady state behaviour (with/ without a moving grounding line), and at comparing model behaviour during the glacial cycles and under enhanced greenhouse warming conditions.

Today, only one or two models exist that deal with the interaction between ice-sheet and ice-shelf flow in an explicit way, but most other models of the Antarctic ice sheet contain some or other ad-hoc treatment to find the position of the grounding line.

As such, the experiments first of all concern 3D time-dependent thermomechanical models with a coupled ice shelf, but part of the experiments can also be performed by models without thermomechanical coupling (vertically integrated) or by models that only consider grounded ice-sheet flow (with/ without a moving grounding line).

A preliminary version of this document was originally prepared by Michael Verbitsky.

2. The model domain

The model calculations are performed on a square grid that is laid out over a polar stereographic projection with standard parallel at 71°S, which coincides with the domain of the Drewry (1983) map folio. The grid is centred at the pole and comprises a 141 x 141 gridpoint matrix. The gridpoint distance is 40 km (Huybrechts, 1992). The following transformation formulas apply between geographical and map coordinates:

$x = 2Rk\tan(\pi/4 + \phi/2)\sin\lambda$

$y = 2Rk\tan(\pi/4 + \phi/2)\cos\lambda$

$\phi = \arcsin(-\cos c)$

$\lambda = \arctan(x/y)$

c = 2arctan ((x**2+y**2)**0.5/(2Rk))

$i = x/\Delta x + 71$ $\qquad$ $j = y/\Delta y + 71$

ϕ = latitude, negative in southern hemisphere

λ = longitude, increases clockwise

R = 6371221 m
k = 0.9728

Δx = 40000 m

Δy = 40000 m

3. Data

3.1. Geometric datasets (Huybrechts, 1992; 1993):

Bedrock elevation:	**bed40eis.dat**
Surface elevation:	**sur40eis.dat**
Ice thickness:	**thi40eis.dat**
Ice mask:	**mask40eis.dat**

These files are written as follows: 1st record: title
2nd record: Fortran format to read one row
record 3 to 2681: data for 141 rows, written as 141 blocks consisting of the row number, which is followed by 18 records with data for the 141 columns.

An easy way to read these data would be:

```
      REAL DATA(NX,NY)
      CHARACTER*80,TITLE,FMT
      READ(1,1000)TITLE
      READ(1,1000)FMT
      DO 2000 J=1,NY
 2000 READ(1,FMT)KDUM,(DATA(I,J),I=1,NX)
 1000 FORMAT(A80)
```

where NX=141, NY=141.

3.2. Forcing during glacial cycles: **foranteis.dat**

This file contains 2201 records with forcing data over last two glacial cycles at a 100-year resolution (220 ky BP - present). First column = year; second column = SPECMAP sea-level (m); third column = Vostok temperature change (deg. C).

3.3. Surface temperature (Huybrechts, 1993) :

mean annual temperature Ta (in deg C):
Ta = 34.46 - 0.00914*Hsur -0.68775*latitude

summer temperature Ts (in deg. C):
Ts = 16.81 - 0.00692*Hsur - 0.27973*latitude

where Hsur is surface elevation and latitude is taken positive

3.4. Accumulation rate [m/y of ice equivalent], after Huybrechts and Oerlemans (1988):

M = 1.5 * 2**(Ta/10)

4. Experiments

We consider 4 different experiments:

<u>Level two:</u> the present-day control experiment with a fixed grounding line and a prescribed set of parameters

<u>Level three:</u> three experiments with the models as they are with a preferred set of parameters and degrees of freedom (present-day equilibrium, glacial cycle, response to enhanced greenhouse warming)

4.1. Control experiment: present-day equilibrium

The initial condition is given by the present surface and bedrock topography. For the first test (level two), the grounding line is fixed to its present condition by using the mask-file. There is no isostatic compensation of the bedrock, no bottom melting, no heat conduction in the bedrock and no basal sliding. The model is then relaxed to steady state with the prescribed set of parameters given in §5. The criterium for steady state is a change in total ice volume of less than 0.01% in 1000 years.

As the next step, use your preferred model with a preferred set of parameters and as many degrees of freedom as your model allows to simulate as closely as possible the present ice sheet, again in steady state.

4.2. Evolution during the last two glacial cycles

Use the data in forcanteis.dat to force sea-level and temperature and make a simulation over the last two glacial cycles. Initial condition is the one obtained with your preferred model under §4.1.

4.3. Response to enhanced greenhouse warming

The initial ice sheet is the present steady state obtained with your preferred model.

The temperature scenario is identical to the one imposed for the Greenland intercomparison experiments and covers 500 years: between 0 (start of the simulation) and 80 years, the temperature increases with the rate of 0.035 °C/year (2.8°C for 80 years). Between 80 and 500 years, the warming rate is 0.0017°C/year (.714 °C for 420 years). The total temperature increase is 3.514 °C. No sea-level forcing.

5. Model parameters

- Glen's flow law with exponent n = 3 :
  $\varepsilon_{ij} = m.a \exp(-Q/RT^*)\, \tau^2\, \tau'_{ij}$ with:
  m = 5
  $T^* < 263.15$ K a $= 1.14\ 10^{-5}$ $Pa^{-3}a^{-1}$ Q = 60 kJ mol^{-1}
  $T^* > 263.15$ K a $= 5.47\ 10^{10}$ $Pa^{-3}a^{-1}$ Q = 139 kJ mol^{-1}

- gravity: 9.81 m s^{-2}
- ice density: 910 kg m^{-3}
- water density: 1028 kg m^{-3}
- conversion factor for seconds to year: 1 year = 31556926 seconds
- geothermal heat flux: 0.0546 W m^{-2}
- triple point of water: 273.15 K
- thermal conductivity: 2.1 W m^{-1} K^{-1}

- specific heat capacity: 2009 J kg^{-1} K^{-1}
- latent heat capacity: 335 kJ kg^{-1}
- dependence of the pressure melting point on depth: $T^* = 273.15 - 8.7 \times 10^{-4}$ x depth

6. Format of results

All results are to be put on the anonymous ftp server at the Vrije Universiteit Brussel:

ftp.vub.ac.be (134.184.129.7)

on the directory: **/pub/exchange**

These files will only remain there for 10 days and file names are not visible, so please send an E-mail to Philippe Huybrechts to warn that data have been sent, together with a list of the file names.

There are several types of results: snapshots (horizontal fields and transect) and time dependent variables. Participants should also provide a file with information concerning their model: characteristics, model parameters, references, etc...

File names are to be coded as follows:

wwxxyyzz.name

where **ww** refers to the type of data:
hf = 2d horizontal field
ht = horizontal transect
ts = time series

where **xx** refers to the type of experiment:
cr = control run (prescribed set of parameters)
er = control run (preferred model)
gc = glacial cycle simulation (preferred model)
gw = greenhouse warming (preferred model)

where **yy** refers to the time:
t000 = steady state (cr/ er) or present (gc)
t125 = Eemian minimum (in area)
t060 = -60 ka
t016 = Last Glacial Maximum (in area)
t006 = -6 ka
t100 = +100 years
t500 = +500 years

where **zz** refers to the type of variable **(only hf)**:
se = surface elevation (m)
it = ice thickness (m)
be = bed elevation (m)
st = surface temperature (°C)
bt = basal temperature (relative to melting) (°C)
ac = surface mass balance (m/y ice equivalent)
vm=vertically averaged velocity magnitude (m/y)

and **name** has a length of maximally 5 characters based on your name or group

For example, the file **htert000.phil** contains my data for the horizontal transect of the control run with my preferred model in steady state.

In addition, the file **info.name** will contain the specific information on your model.

6.1. Horizontal fields

These files should be written in the same way as the input files, with the data written in format F10.4. Data are required for:

1. surface elevation (m)
2. ice thickness (m)
3. bed elevation (m)
4. surface temperature (°C)
5. basal temperature (relative to melting) (°C)
6. surface mass-balance
7. vertically averaged velocity magnitude (m/y)

<u>An appropriate way to write these files is:</u>

```
      REAL DATA(NX,NY)
      WRITE(1,1000)
      WRITE(1,1001)
      DO 100 J=1,NY
 100  WRITE(1,1002)J,(DATA(I,J),I=1,NX)
 1000 FORMAT('TITLE')
 1001 FORMAT('(I5,/,17(8F10.4,/),5F10.4)')
 1002 FORMAT(I5,/,17(8F10.4,/),5F10.4)
```

where NX=141, NY=141.

Outside the area of interest (e.g. in the ice shelf or ocean area) use the undefined value of **999.9999**

6.2. Horizontal transects

This is for a transect which cuts across the West Antarctic ice sheet, the Ross Ice Shelf and the East Antarctic ice sheet, for J=51.

Format of the file:

line 1: nz (# gridpoints in vertical direction)
line 2 ->142:   from i=1 to i=141

i	column 1
surface elevation (m)	column 2
ice thickness (m)	column 3
bed elevation (m)	column 4
elevation of ice bottom (m)	column 5
surface temperature (°C)	column 6
surface mass balance (m/y i.e.)	column 7
vertically averaged velocity (m/y)	column 8

line 143 -> end: from i = 1,141
from surface to bottom

i	column 1	
z position (m)	column 2	
x-velocity (m/y)	column 3	
y-velocity (m/y)	column 4	
z-velocity (m/y)	column 5	
temperature (°C)	column 6	(relative to melting)

Columns are separated by at least one blanc.

6.3. Time-dependent files

Data every 100 years for the steady state runs and the glacial cycle simulations
Data every 10 years for the greenhouse warming scenarios

These files contain data in format: **(1x, f8.0, 3(1x,e14.6), 1x, f8.4, 2(1x, f7.4))**

1. time (years)
2. grounded ice area (m^2)
3. grounded ice volume (m^3)
4. area of grounded ice at pressure melting point (m^2)
5. mean basal temperature of grounded ice, relative to melting (°C)
6. mean accumulation rate over grounded ice (m/y ice equivalent)
7. mean ablation rate over grounded ice (if any) (m/y ice equivalent)

7. Addresses

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8. References

Drewry, D. (1983): Antarctic glaciological and geophysical folio. Scott Polar Research Institute (Cambridge).

Huybrechts Ph. and J. Oerlemans (1988): Evolution of the East Antarctic ice sheet: a numerical study of thermo-mechanical response patterns with changing climate, Annals of Glaciology 11, 52-59

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Huybrechts Ph. (1993): Glaciological modelling of the Late Cenozoic East Antarctic Ice Sheet: stability or dynamism?, Geografiska Annaler 75 A (4), 221-238.