Vincent ROMMELAERE
Laboratoire de Glaciologie et
Géophysique de l'Environnement, CNRS,
54, rue Molière BP 96
38402 Saint Martin d'Heres cedex
FRANCE
E-mail: vince@glaciog.grenet.fr

ICE SHELF MODELS INTERCOMPARISON
SETUP OF THE EXPERIMENTS[1]

The tests proposed below were defined and discussed during an EISMINT workshop held in Brussels (March 29-30th). The purpose of these tests is not to give an overview of what can be done in ice-shelf modeling, but rather to fix benchmarks for future modeling attempts and to detect weakness in the approaches that are commonly used. The experiments may be somewhat restrictive and may not be appropriate for all kinds of model. All suggestions to improve this setup are of course welcome.

I - Tests on ideal geometry

This part is designed to check (whenever possible, meaning when an analytical solution is available) and to compare the results of different models in simplified conditions. The thread of these tests is to simulate the response of an ice-shelf due to a fluctuating ice-stream discharge.

1- Mass conservation

a) tests 1-2

As far as I know, all ice-shelf models treat the Stokes' equations and the ice mass conservation independently (basically ice-shelf models have two governing equations instead of one for grounded ice sheet models). The following test is a classical means to see how accurate is the advection scheme (or mass conservation scheme, in our case). Let's consider a square ice shelf with a fixed velocity field. An ice-stream is fluctuating at a boundary of the domain and we want to check whether or not our conservation scheme is able to propagate the signal of the ice-stream along the ice shelf.

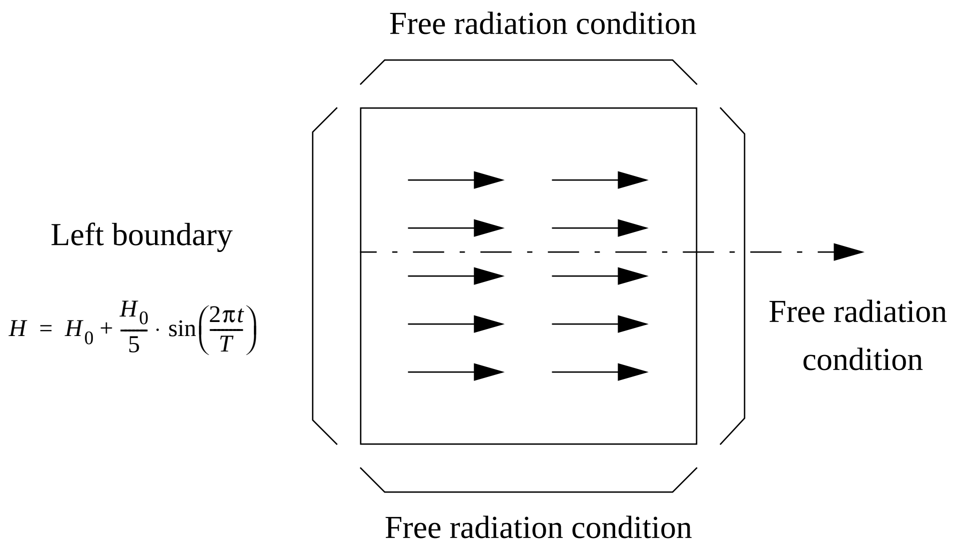
parameters of run 1
- L=200km (length and width of the ice-shelf).
- velocity field: (u_0, 0) with u_0=400m/a
- initial thickness field: H_0 = 500m
- period of fluctuation: T=200 years
- let the system evolve during 500 years (=2.5T)
- numerical resolution: (FD: 41x41 gridpoints or an equivalent number of nodes for FE).

[1] This is an evolving document. An updated version (postscript file) can be accessed by anonymous ftp on alaska.grenet.fr (130.190.75.2) in the /pub/EISMINT2 directory.

- time step: user's choice, but it has to be less than dx/u_0; a value of 10 years should be accurate.

<u>parameters</u> of run 2:

The same as in the previous run, but with a resolution of 81x81 gridpoints (or its equivalent in terms of number of nodes). A time step of 5 years is recommended.



NB1: this is a one-dimensional problem which can also be performed to test a flow-line model.

NB2: The analytical solution (wave propagation equation) is: $H(x, y) = H_0 + \frac{H_0}{5} \cdot \sin\left(\frac{2\pi}{T} \cdot \left(t - \frac{x}{u_0}\right)\right)$

<u>b) tests 3-4</u>

In two dimensions, problems with the numerical treatment of conservation laws may arise when fluxes are not perpendicularly to a grid cell. Tests 3 and 4 are formally identical to test 1 and 2 but with a rotation of the numerical domain.

<u>parameters</u> of run 3:

- initial thickness field: constant thickness of 500m.
- velocity field (u_1,v_1), with $u_1 = 160 \cdot \sqrt{5}$ m/a and $u_1 = 80 \cdot \sqrt{5}$ m/a.
- period of fluctuation: T=200 years
- let the system evolve during 500 years (=2.5T)
- numerical resolution: (FD: 41x41 gridpoints or an equivalent number of nodes for FE).
- recommended time step: 10 years.

<u>parameters</u> of run 4:

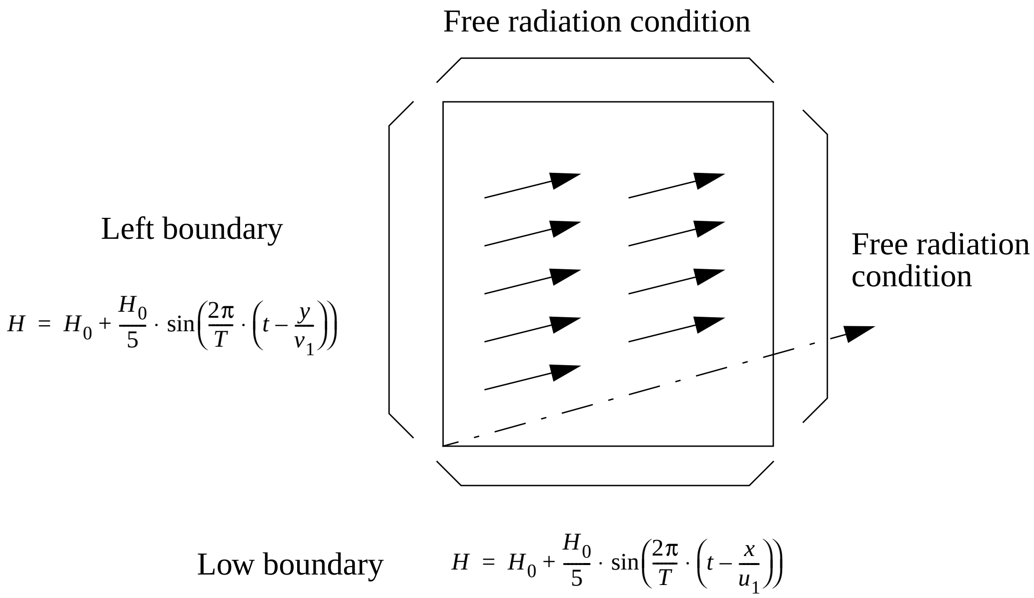
The same as in the previous runs but with a higher resolution (81x81 gridpoints or equivalent number of nodes)

recommended time step: 5 years.

<u>c) format of the results</u>

For each run, I would like the participant to provide me the following files:

✔ adv$n$c.$name: where $n is the test number (from 1 to 4), $c is a character you may have to use if you test several schemes and $name is the participant's name.



<u>examples:</u> - adv1a.vince for the first algorithm used by Vince to solve test 1.
- adv3p.pamela for the sixteenth algorithm used by Pamela to solve test 3.

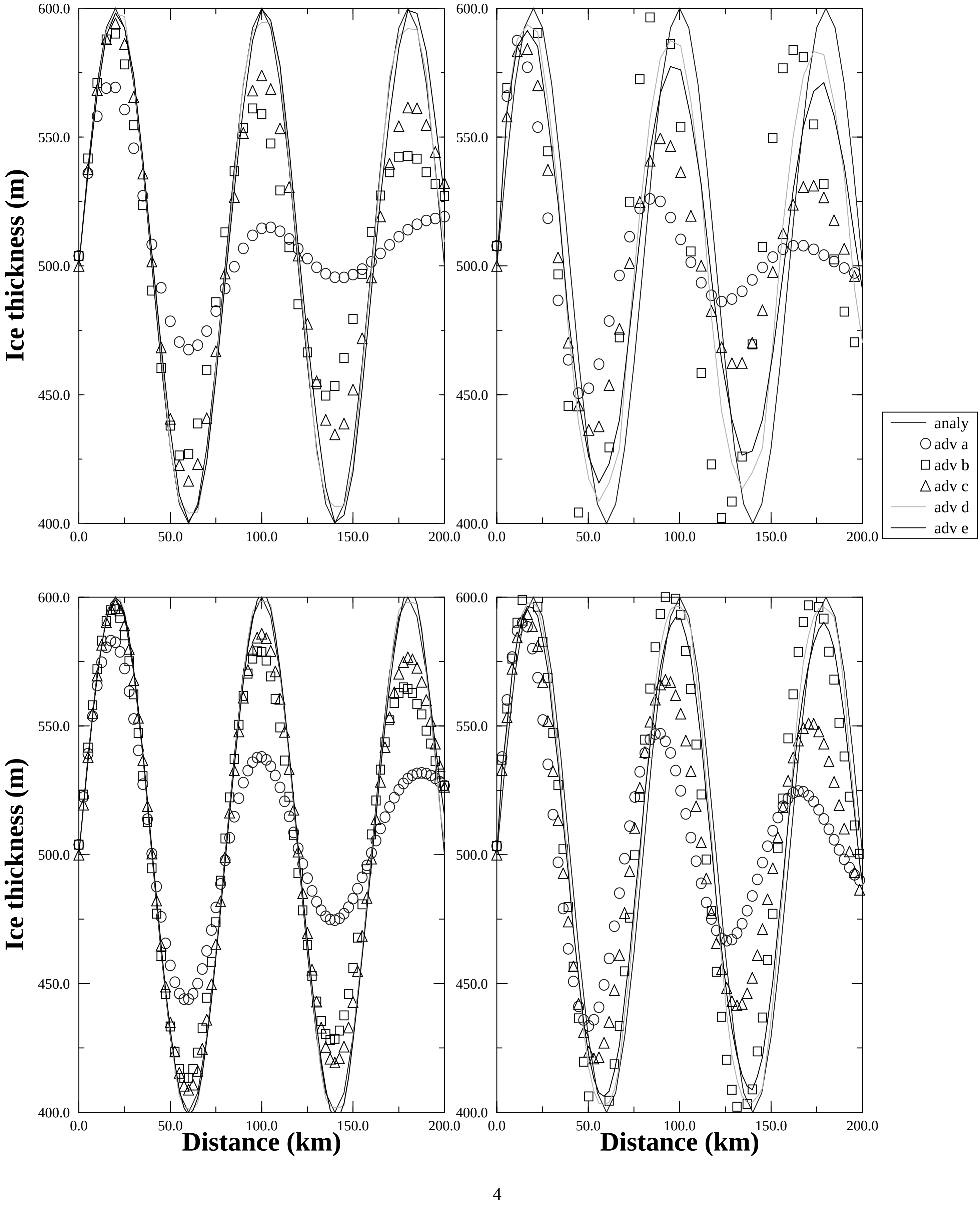
This file should contain data in two columns, without any separator (such as : or ;) in between. The first column contains the x-coordinates in km, the second contains the ice thickness in meters. The x-coordinates and thickness are taken along a cross section in the direction of the wave propagation. For test 1 and test 2, pick the gridpoints x-coordinates in the middle of the numerical domain (i=21 for FD). For test 3 and test 4, pick the x-coordinates (and the thickness values) along a line 2j-i=1 (the X-axis, on which the thickness values have to be taken, is represented by the dashed-dotted arrow on the figures)

✔ A short note of explanation on the different algorithms which were used: which one seems to be the best, why such algorithm is not suited to the problem, and conclusions about the scheme and the resolution which should be used for the «fluctuating ice stream problem».

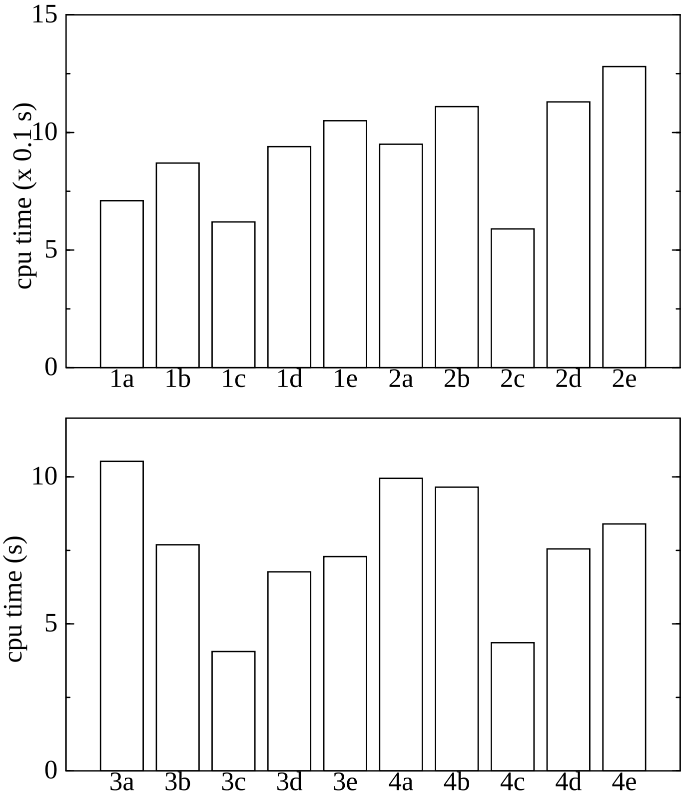
✔ A summary of the performance of each algorithm. The best would probably be to provide the number of floating operations required by each scheme, but I don't know how to do this on my HP. So, A list of CPU time and on what kind of machine will be enough. This is just designed to have an idea on the «limits» of each algorithm.

<u>d) preliminary results</u>

I performed these tests and plotted the results (compared to the analytical solution) on the following pages. The surprising thing, which came to me, is that the schemes (a and b) I was using were not able to reproduce the analytical solution (although I'm convinced that they are sufficient


Ice thickness (m)
600.0
550.0
500.0
450.0
400.0
0.0
50.0
100.0
150.0
200.0
Distance (km)
analy
adv a
adv b
adv c
adv d
adv e

when we only want to treat the steady state problem). This surprise was for me the opportunity to test three other schemes. At least two of them (run d and e) are much better reproducing the analytical solution. The results of test 3 and 4 suggest that scheme d with a high resolution is the most adapted to the problem. (And thus the conservation scheme I'm going to use for the next parts).



2- Diagnostic equations

This is the second type of governing equations in an ice-shelf model. In this part, we try to compute the depth averaged velocity field from a prescribed ice thickness field and prescribed boundary conditions. The ice-shelf we shall study has the same dimensions as in the previous part.

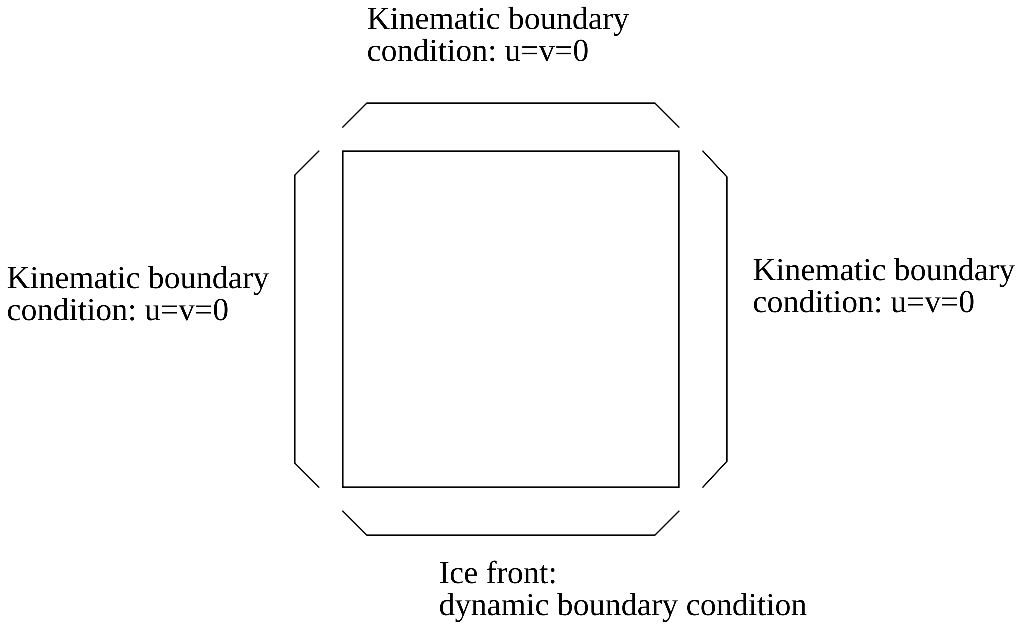
a) test 1-2

First, we shall ignore the rheological properties of ice and we shall consider ice as a newtonian viscous fluid (constant viscosity).

parameters:

- ice density: 917 kg/m3.
- sea water density: 1028 kg/m3.
- gravity acceleration: g=9.81 m.s^{-2}.
- initial ice thickness field: 500m.
- ice viscosity : 25 MPa.a (order of magnitude of what is observed on the Ross Ice Shelf)
- resolution: 41 by 41 for test 1, 81 by 81 for test 2

NB: I don't think there is any analytical solution to this problem. However, the symetry of the results can be checked.



b) test 3-4

Same geometry, same resolution, same boundary conditions, but ice is now considered as an isotropic material following Glen's flow law.

<u>parameters:</u>

- ice viscosity: $\eta = \frac{A_T^{-\frac{1}{3}}}{2 \cdot \dot{\varepsilon}^{\frac{2}{3}}}$ with $A_T = 5.7 \times 10^{-18}$ $Pa^{-3}a^{-1}$ (corresponding to an isotherm ice-shelf at 253K).

ε is the second invariant of the strain rate tensor.

<u>c) test 5-6</u>

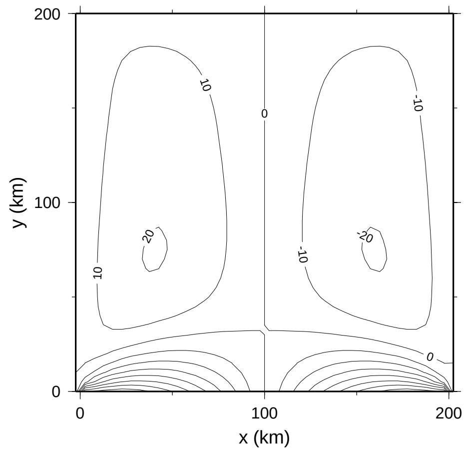
In the previous run, the upper boundary condition is changed to account for an ice stream entering the ice-shelf. The x-velocity u is unchanged (equal to 0 everywhere on the upper boundary). The upper boundary condition for y-velocity becomes the following:

$$v(x, (y = L)) = v_{max} \cdot \left(\left[\frac{x - x_m}{x_w} \right]^2 - 1 \right) \cdot Heav\left(1 - \left[\frac{x - x_m}{x_w} \right]^2 \right)$$

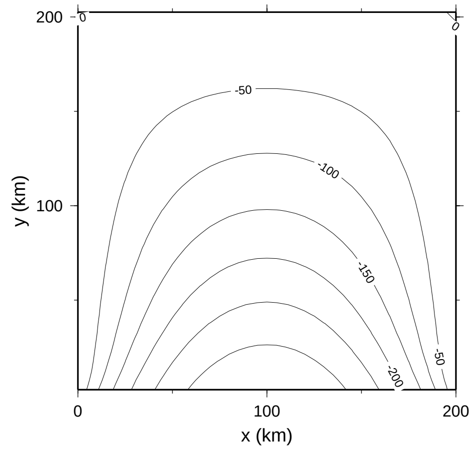
where Heav is the Heaviside (or «step») function, x_w is the half-width of the ice-stream and x_m the coordinate of its center. Note that v has to be negative.

<u>parameters:</u>

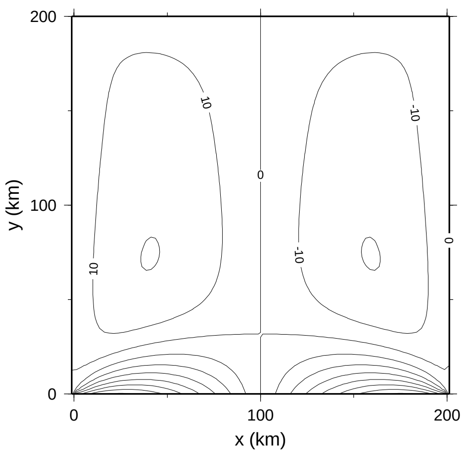
- v_{max} = 400 m/a
- x_m = 100 km
- x_w = 25 km



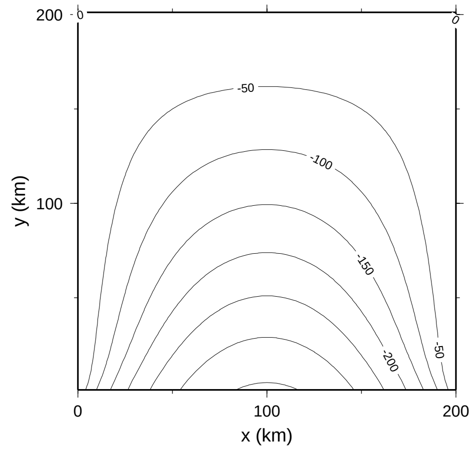
Horizontal x-velocity (u) in m/a - test 1



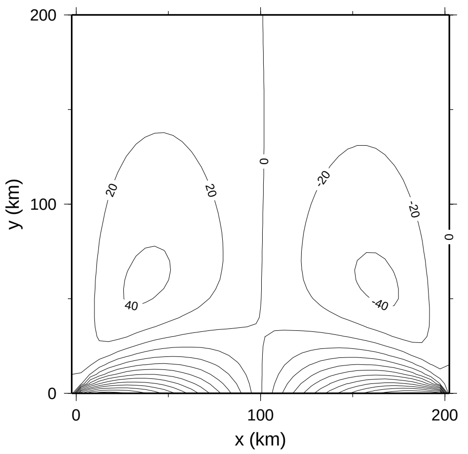
Horizontal y-velocity (v) in m/a - test 1



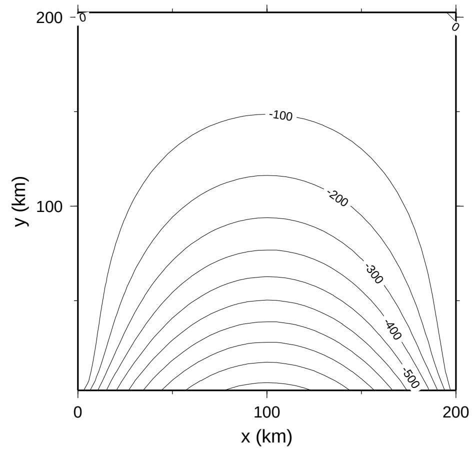
Horizontal x-velocity (u) in m/a - test 2



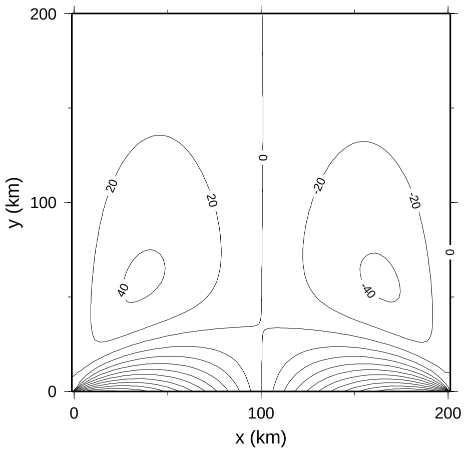
Horizontal y-velocity (v) in m/a - test 2



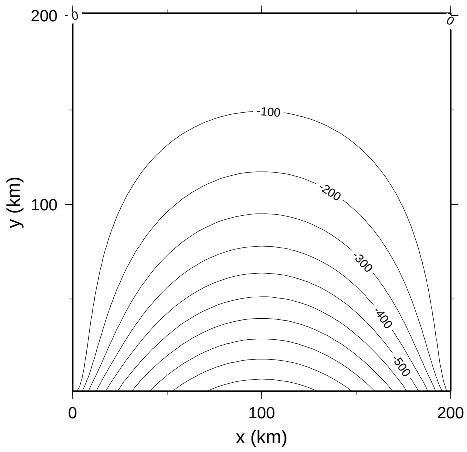
Horizontal x-velocity (u) in m/a - test 3



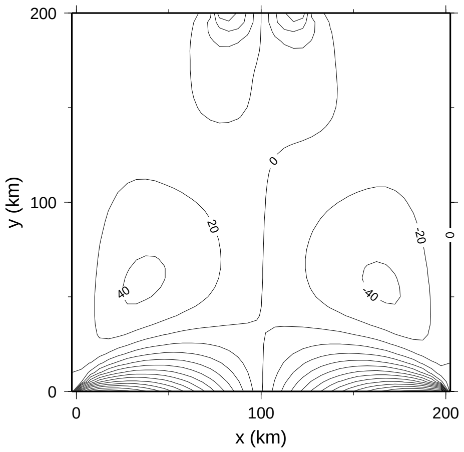
Horizontal y-velocity (v) in m/a - test 3



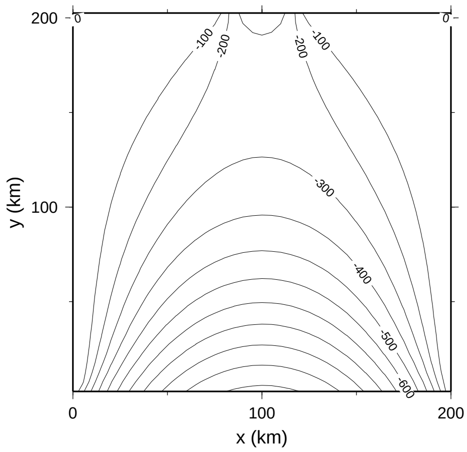
Horizontal x-velocity (u) in m/a - test 4



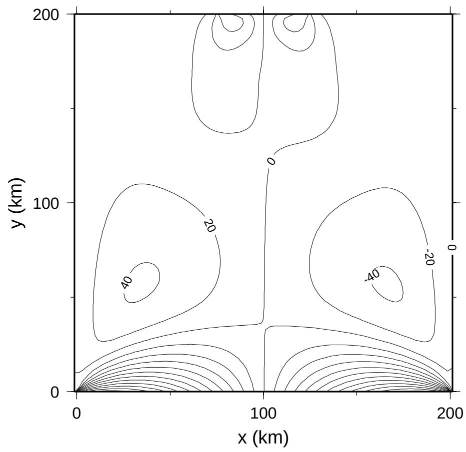
Horizontal y-velocity (v) in m/a - test 4



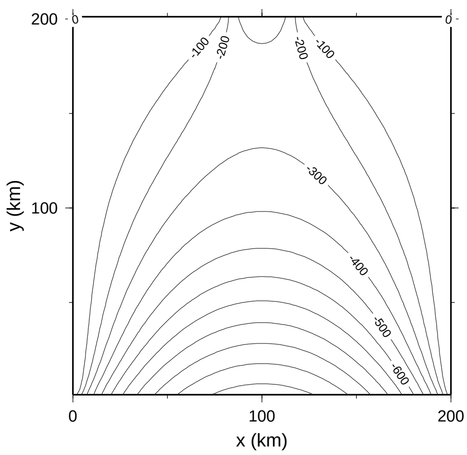
Horizontal x-velocity (u) in m/a - test 5



Horizontal y-velocity (v) in m/a - test 5



Horizontal x-velocity (u) in m/a - test 6



Horizontal y-velocity (v) in m/a - test 6

<u>*d) results*</u>

For each run, I would like the participant to provide me the following files:

✔ dia$n$c.$name: where $n is the test number (from 1 to 6), $c is a character you may have to use if you test several schemes and $name is the participant's name. This file contains data in four columns (without any separator such as : or ;): x-coordinates (km), y-coordinates (km), x-velocity component (m/a)and y-velocity component (m/a).

✔ A short note of explanation on the different algorithms which were used: is it a direct or indirect (e.g. iterative) method of resolution, which scheme seems to be the best, why such algorithm is not suited to the problem, and conclusions about the scheme and the resolution which should be used for the «fluctuating ice stream problem».

✔ A summary of the performance of each algorithm.

3- Coupled model of ice-shelf flow

<u>*a) test 1*</u>

With the parameters defined in run 5-6 in the previous part (diagnostic equations), let the system evolve and reach asteady state (5000 years). The accumulation rate is set to a constant value of 0.2 m/a (ice equivalent).

<u>*b) test 2: fluctuating ice stream problem*</u>

From the steady state obtained above, make the ice-stream fluctuate by changing the maximum velocity of the ice-stream with time (1000 years evolution):

$$v_{max} = 400 + 100 \cdot \sin\left(\frac{2\pi}{T} \cdot t\right)$$

v_{max} is in m/year

<u>*c) back-force*</u>

I would like the participants to define, according to them, what is the global force (in N) which restrain the ice-shelf in its embayement. The evolution of this «back-force» (whatever it is) should then be computed at each time step to provide an estimation of the ice-shelf response to changing conditions of an ice-stream - test 2 - (Is this response linear with changes in the ice-stream dynamics? Can we expect some kind of «hysteresis» in the back-force?).

<u>*d) results*</u>

✔ - std.$name: file in five columns: x-coordinates (km), y-coordinates, x-velocity component (m/a), y-velocity component and ice thickness of the ice-shelf in steady state.

✔ - flct$t.$name: $t is a number varying from 1 to 7. Files in three columns: y-coordi-

nates, y-velocity component on the center line and ice thickness on this center line at different times.
$t=1: 200 years, $t=2: 500 years, $t=3: 600 years, $t=4: 700 years, $t=5: 800 years, $t=6: 900 years, $t=7: 1000 years.

✔ - bck.$name: file in two columns: time (in years, a time step of 20 years would be fine) and «global back-force» (in N) for the fluctuating ice stream problem.

II- Ross Ice Shelf experiment

a) experiment

A dataset of the present (1979) configuration of the Ross Ice Shelf is available for finite elements, as well as for finite differences. The finite difference version may be accessed by anonymous ftp on alaska.grenet.fr in the /pub/EISMINT-INTERCOMP/ICE-SHELVES/ROSS/ directory. The finite element version can be asked to Doug MacAyeal (drm7@midway.uchicago.edu).
I also join a file (visco.ross) which contains what is, according to me, the present effective viscosity of the Ross Ice Shelf.

I would like the participant to perform a time-evolution experiment with the Ross Ice Shelf geometry for the next 200 years. No plausible scenario (changes in temperature, accumulation rates, ice stream discharges, ice viscosity...) is given here and the participant will have to propose one (present configuration, output from 3D Antarctic model, IPCC inspired scenario, ...). This experiment is thus highly subjective, but some special trends may come out of the results.

b) results

✔ - a short note of explanation on the scenario you used.
✔ - ross.$name: file in five columns containing the x-coordinate, y-coordinate, ice thickness (m), x-velocity (m/a), y-velocity (m/a).