

# Glacier Sim

Andrea Bair

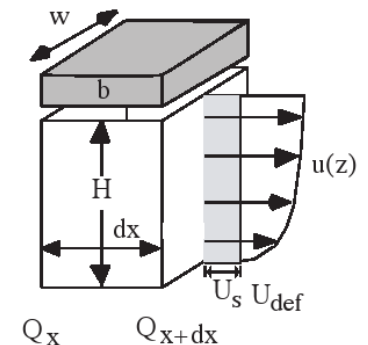
Archie Paulson

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# Basic Model

- The glacier's thickness versus position and time depend on
  - shape of valley floor
  - temperature (a linear function of elevation)
  - precipitation rate (also a linear function of elevation)
- Temperature and precipitation can be combined to form a function called the mass balance, which equals growth (due to precip.) minus ablation (melt and sublimation). The mass balance gives the rate of change of glacier height per unit time as a function of elevation.
- A mass balance which is constant in time results (eventually) in a steady-state glacier. In steady state, the glacier is flowing downhill as it gains ice over its upper half (positive mass balance) and loses ice over its lower half (negative mass balance). The line that divides these two regions is called the “equilibrium line”.
  - The velocity of the ice is nonzero at the bottom of the glacier (due to sliding), and increases with vertical height, as shown in the figure at the right. A simple model can be seen at the following website:

[http://www2.wvnorton.com/college/geo/egeo/flash/18\\_1.swf](http://www2.wvnorton.com/college/geo/egeo/flash/18_1.swf)



File Help



## Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

## Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

## Climate Control

*Snowfall*

none  lots

*Temperature*

cold  hot

• Climate Presets

• Edit Mass Balance

☒ Set glacier to equilibrium state

time elapsed:

123.57 years

time rate:

slow

fast

valley slope:

bump



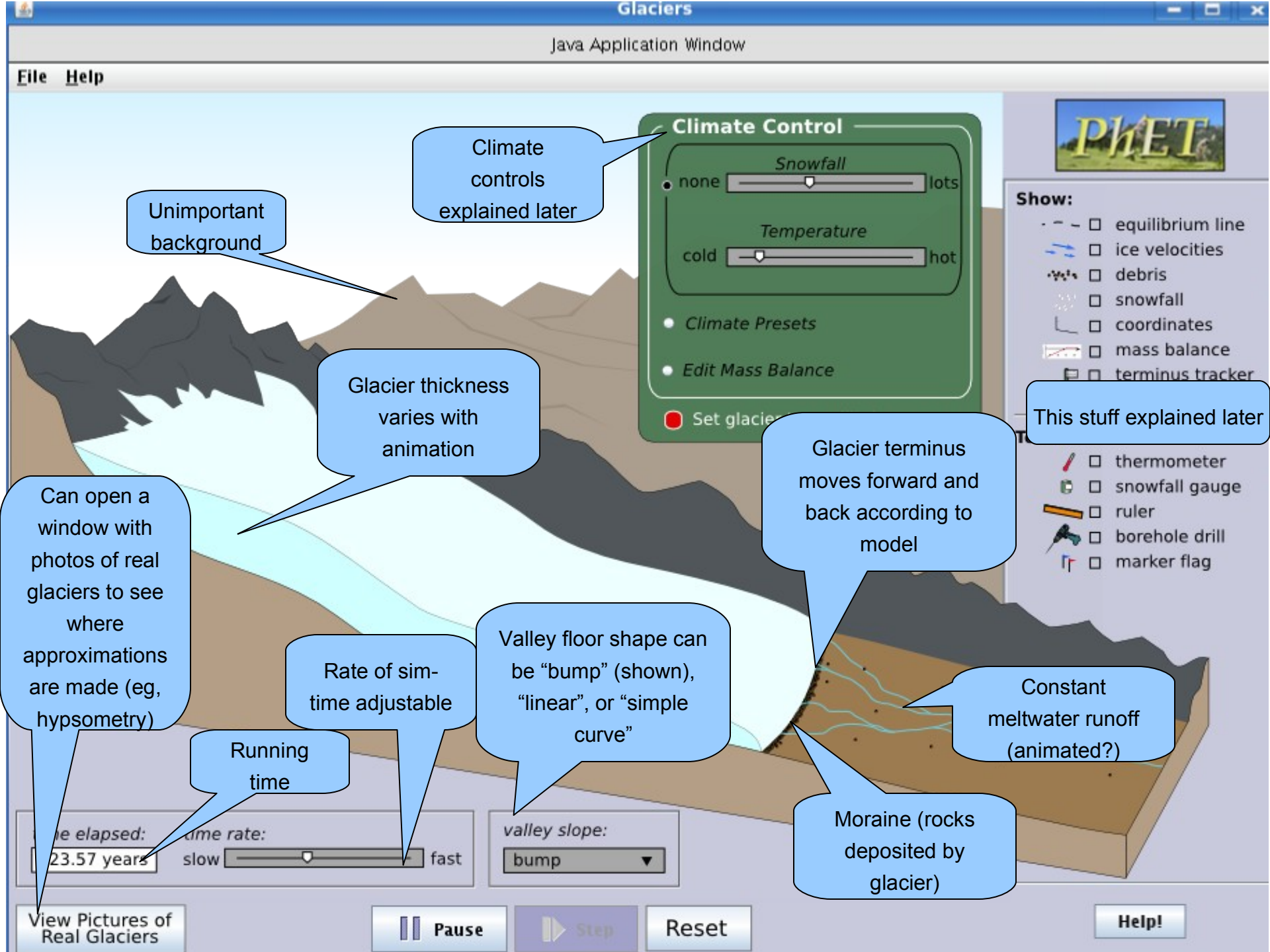
View Pictures of  
Real Glaciers

Pause

Step

Reset

Help!



Unimportant background

Climate controls explained later

Glacier thickness varies with animation

Can open a window with photos of real glaciers to see where approximations are made (eg, hypsometry)

Running time

Rate of sim-time adjustable

Valley floor shape can be "bump" (shown), "linear", or "simple curve"

Glacier terminus moves forward and back according to model

Constant meltwater runoff (animated?)

Moraine (rocks deposited by glacier)

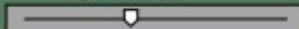
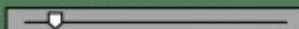
This stuff explained later

File Help

After glacier retreat

Moraine wall  
left behind

## Climate Control

none  lotscold  hot

• Climate Presets

• Edit Mass Balance

☒ Set glacier to equilibrium state

## Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

## Tools:

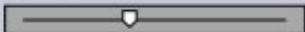
- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

time elapsed:

123.57 years

time rate:

slow



fast

valley slope:

bump

View Pictures of  
Real Glaciers

Pause

Step

Reset

Help!

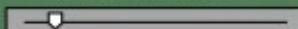


File Help

Glacier is now gone.

## Climate Control

none  lots

cold  hot

• Climate Presets

• Edit Mass Balance

☒ Set glacier to equilibrium state



## Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

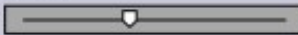
## Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

time elapsed:

123.57 years

time rate:

slow  fast

valley slope:

bump ▼

View Pictures of  
Real Glaciers

|| Pause

▶ Step

Reset

Help!

# Climate Controls

- The green panel controls climate by one of three methods (selected by radio buttons)
  - snowfall and temperature controlled independently (previous slides)
  - climate presets (in drop-down boxes) are selectors for certain values of snowfall & temperature (next slide):
    - “time period” can be “modern day” or “last glacial maximum”
    - “latitude” can be “equitorial” or “temperate” or “polar”
    - “altitude” can be “sea level” or “alpine”
  - edit mass balance by entering the three numeric values that are used to describe the function (after next slide):
    - altitude of the equilibrium line
    - slope of the linear mass balance function
    - maximum value of the mass balance
- Once a climate control is changed, the glacier can be set to be at the steady-state shape for the current climate by pressing the button next to “Set glacier to equilibrium state.” Otherwise, the glacier will evolve in time until the steady-state is eventually achieved.

File Help

Select the middle button to use preset values for snowfall and temperature according to time epoch, latitude and altitude

To force the glacier to go to the steady-state shape, click this red button

### Climate Control

#### • Snowfall & Temperature

Time Period Latitude Altitude 

#### • Edit Mass Balance

☒ Set glacier to equilibrium state

### Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

### Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

time elapsed:

time rate:

slow  fast

valley slope:

[View Pictures of Real Glaciers](#)



File Help

Select the third button to directly edit the mass balance function (which can be described by these three independent values).

## Climate Control

- Snowfall & Temperature
- Climate Presets

Equilibrium Line Altitude  mMass Balance Slope  m/yr/kmMaximum Mass Balance  m/yr☒ Set glacier to equilibrium state

## Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

## Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

time elapsed:

time rate:

slow  fast

valley slope:

[View Pictures of Real Glaciers](#)

# “Show” Options

In the “Show” panel, the user can click one or more of the boxes. Results are shown in the slides following this one.

- “equilibrium line” shows the altitude of zero mass balance.
- “ice velocities” shows a vector field of current ice velocity at all positions within the ice.
- “debris” shows rocks which will flow along with the ice velocity and be deposited at the terminus.
- “snowfall” will show the animated falling snow above the equilibrium line altitude (ELA).
- “coordinates” will show elevation on the vertical axis and distance on the horizontal axis.
- “mass balance” will pop up a window that shows the mass balance function.
- “terminus tracker” will show an arrow with the current horizontal position and velocity of the glacier terminus.

File Help

Velocity vectors of ice flow

Equilibrium Line Altitude (ELA) can be shown

### Climate Control

- Snowfall & Temperature
- Climate Presets

Equilibrium Line Altitude  m

Mass Balance Slope  m/yr/km

Maximum Mass Balance  m/yr

☒ Set glacier to equilibrium state

### Show:

- ☒ equilibrium line
- ☒ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

### Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

time elapsed:

123.57 years

time rate:

slow  fast

valley slope:

bump ▼

View Pictures of  
Real Glaciers

Pause

Step

Reset

Help!

File Help

Rocks entrained in ice  
and riding along on top.  
The debris moves at the  
speed of the ice flow.

## Climate Control

- Snowfall & Temperature
- Climate Presets

Equilibrium Line Altitude  mMass Balance Slope  m/yr/kmMaximum Mass Balance  m/yr☒ Set glacier to equilibrium state

## Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☒ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

## Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

Rocks deposited at  
terminus, forming  
moraine

time elapsed:

time rate:

slow  fast

valley slope:

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Real Glaciers](#)



File Help

Snowfall is animated

Snowfall goes no lower than the ELA (no net accumulation below this line)

## Climate Control

- Snowfall & Temperature
- Climate Presets

Equilibrium Line Altitude  m

Mass Balance Slope  m/yr/km

Maximum Mass Balance  m/yr

☒ Set glacier to equilibrium state



## Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☒ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

## Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

time elapsed:

time rate:

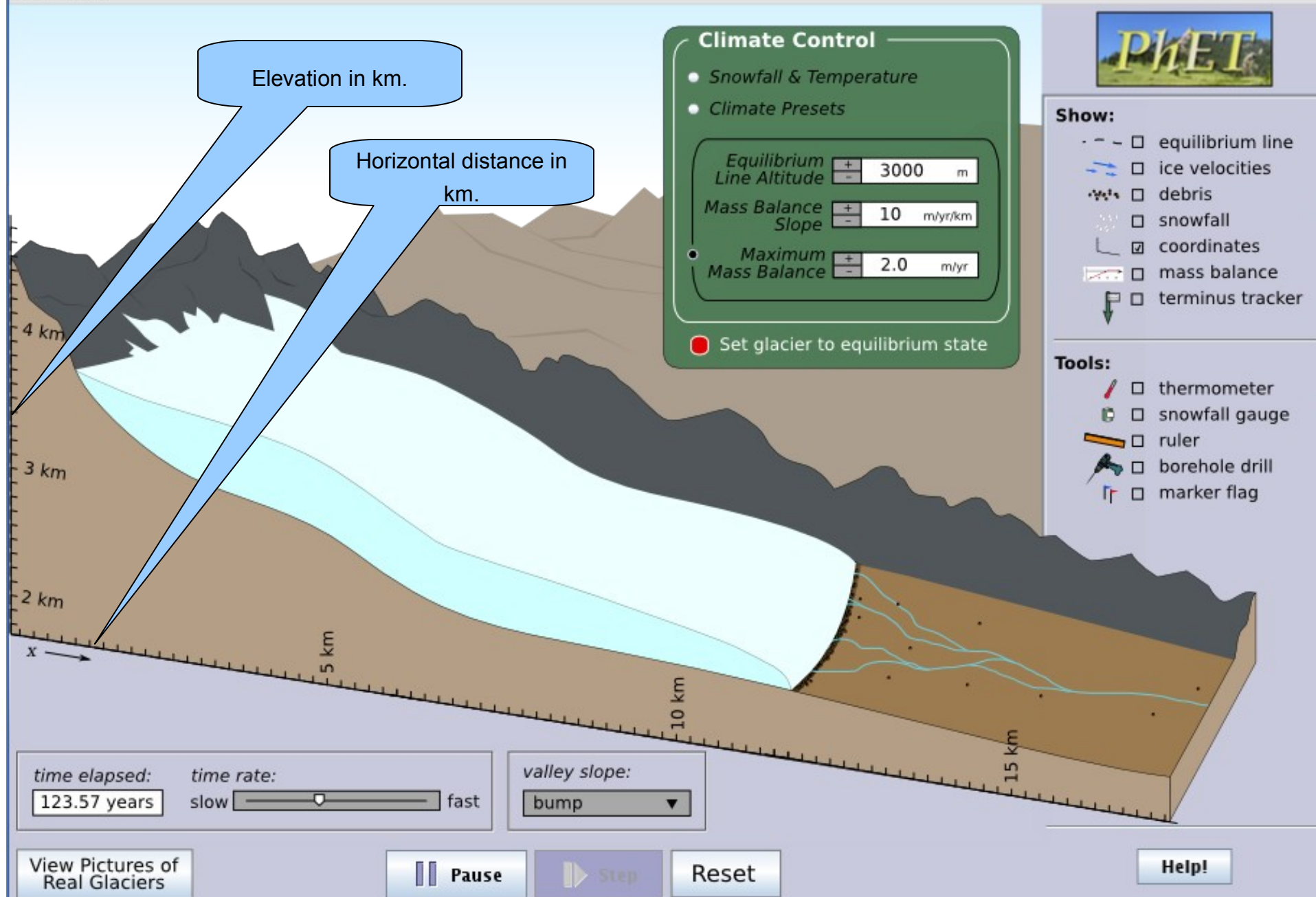
slow  fast

valley slope:

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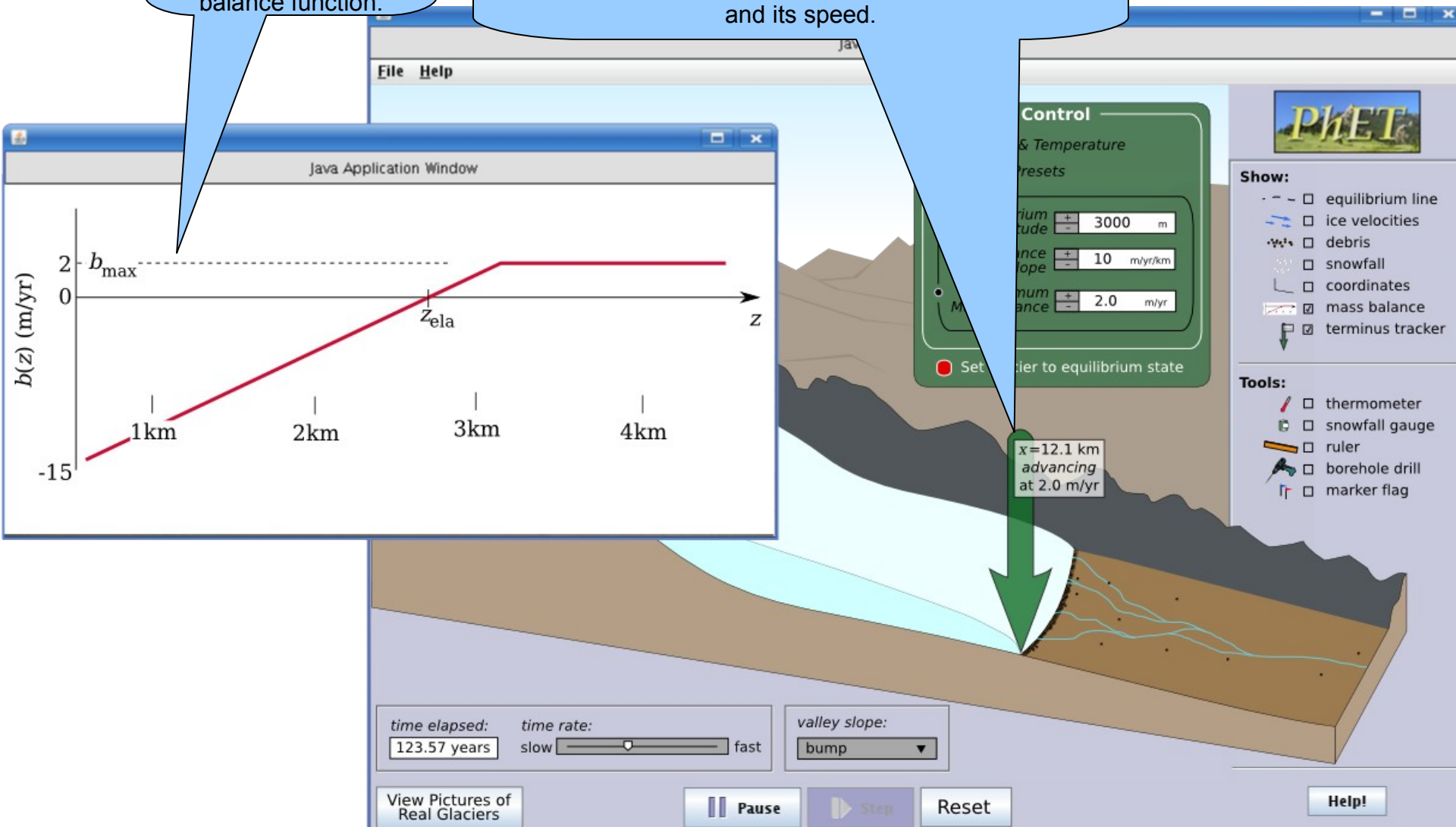


File Help



Pop-up window shows the mass balance function.

When "terminus tracker" is checked, a green arrow follows the terminus motion, reporting its x-location and its speed.



# “Tool” Options

In the “Tool” panel, the user can click one or more of the boxes. Results are shown in the slides following this one.

- “thermometer” gives a temperature-measuring tool. It can be dragged around and reports the atmospheric temperature. It should be excluded from the cross-section region since we don't keep track of ice temperatures.
- “snow gauge” looks like a bucket. It can be dragged around and reports the local net snow accumulation.
- “ruler” gives a distance-measuring tool.
- “marker flag” allows the user to plant flags. On ice the flag will move with the ice flow – this flag will be blue. On the ground a red flag can be planted (to mark the terminus at some time, for example) – this flag can be covered and uncovered by the glacier.
- “borehole drill” is a tool to drill vertical boreholes in the ice. It will start out as a vertical column and then deform, showing the differential velocities of the ice flow (see the little figure in the corner of the second slide).

File Help

Shows rate of  
snow/ice  
accumulation.

Shows local  
(adiabatic)  
temperature.

### Climate Control

- Snowfall & Temperature
- Climate Presets

Equilibrium  
Line Altitude  m

Mass Balance  
Slope  m/yr/km

Maximum  
Mass Balance  m/yr

☒ Set glacier to equilibrium state



### Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

### Tools:

- ☒ thermometer
- ☒ snowfall gauge
- ☐ ruler
- ☐ borehole drill
- ☐ marker flag

1.2 m/yr

8.0 °C

time elapsed:

123.57 years

time rate:

slow  fast

valley slope:

bump ▼

View Pictures of  
Real Glaciers

Pause

Step

Reset

Help!



File Help

Ruler can be used to measure ice thickness at a given location.

When "marker flag" is checked, clicking will plant a flag (blue on ice, red on ground).

### Climate Control

- Snowfall & Temperature
- Climate Presets

Equilibrium Line Altitude  m

Mass Balance Slope  m/yr/km

Maximum Balance  m/yr

☒ Set glacier to equilibrium state

### Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
- ☐ coordinates
- ☐ mass balance
- ☐ terminus tracker

### Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☒ ruler
- ☐ borehole drill
- ☒ marker flag

Blue flags move with the ice.

Red flags stay on the ground (can be covered and uncovered by ice).

time elapsed:

time rate:  
slow

View Pictures of  
Real Glaciers

Pause

Reset

Help!



File Help

The drill will make a vertical borehole. The hole will then begin to show the shape of the vertical velocity profile of the ice flow.

## Climate Control

- Snowfall & Temperature
- Climate Presets

Equilibrium Line Altitude  mMass Balance Slope  m/yr/kmMaximum Mass Balance  m/yr☒ Set glacier to equilibrium state

## Show:

- ☐ equilibrium line
- ☐ ice velocities
- ☐ debris
- ☐ snowfall
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- ☐ mass balance
- ☐ terminus tracker

## Tools:

- ☐ thermometer
- ☐ snowfall gauge
- ☐ ruler
- ☒ borehole drill
- ☐ marker flag



time elapsed:

time rate:

slow  fast

valley slope:

[View Pictures of Real Glaciers](#)

## Other Options (which would be nice)

- change between the perspective view (is all slides above) to just the side view
- zoom in so that the borehole deformation is clearly visible
- show age of ice with contour lines (or colors?)
- velocity vectors could also appear on glacier surface to show lateral variation in flow
- marker flags could record the time of planting (for making measurements)
- climate control should have an option to set a time-dependent history; for example, set a beginning climate and an ending climate (with a time for each), then the snowfall and precip. are interpolated between the end-members

# The End

That concludes the sim specification (as it exists so far). The remaining slides include motivations for this sim, including student difficulties, learning goals, and animations that exist on the web.

# Student learning difficulties/misconceptions

- Glaciers form only where it is very cold, and disappear with warming (not related to amount of snowfall)
- Glaciers only form at high elevations or latitudes (T control); cannot form near sea level or at low latitudes (perhaps more a problem in Colorado, where most instructor examples are of alpine glaciers).
- A glacier is a pile of ice that sits there once it forms; dynamics of ice movement in a “steady-state” glacier not known.
- Glacial retreat means that ice is not moving but just melting back, or that the ice is literally moving uphill.
- No sense of how long it takes glaciers to form, or change.
- More melting (more water) makes a glacier flow faster; thus, increased temperature can make the whole thing slide downhill.

# Learning Goals and objectives

- Describe how glaciers form, grow, and shrink – specify what environmental conditions lead to each.
  - Identify where net ablation ( $\sim \text{melting} > \text{snowfall}$ ) and accumulation ( $\sim \text{melting} < \text{snowfall}$ ) occur in relation to the Equilibrium Line Altitude (ELA).
  - Explain or illustrate how glaciers form.
  - Describe the most important controls on mass balance in a glacier.
  - Analyze the relationship between temperature and the likelihood of snow vs. rain at given parts of a glacier.
- Explain how ice moves within a glacier (describe and illustrate the mass balance of a glacier).
  - Describe and illustrate how glacial ice moves.
  - Qualitatively describe the relationship between the speed of ice flow and with ice thickness, and predict where ice is oldest.
- Describe why and how valley glaciers “advance” or “retreat”. When the glacier retreats, does ice move up the glacial valley?
  - Compare and contrast motion of ice when a glacier is (1) at equilibrium, (2) advancing, and (3) retreating.
  - Compare and contrast climatic conditions leading to glacial (1) equilibrium, (2) advance, and (3) retreat.
- Determine how multiple advance-retreat cycles affect the record of glacial moraines (end moraines).
  - Describe how end moraines form.
  - Discuss how more recent, large advances can impact moraines left by older, smaller advances.
  - Given an illustration of 3-4 end moraines, determine the most likely order of their formation and justify your ordering.



# Existing Animations

**Existing examples of animations for comparison:**

<http://www2.wwnorton.com/college/geo/egeo/animations/ch18.htm>

<http://www.uky.edu/AS/Geology/howell/goodies/elearning/module13swf.swf>

[http://highered.mcgraw-hill.com/sites/0072402466/student\\_view0/chapter12/animations\\_and\\_movies.htm](http://highered.mcgraw-hill.com/sites/0072402466/student_view0/chapter12/animations_and_movies.htm)