The Parallel Ice Sheet Model as a flow-line model

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Synopsis

Flow-line models have several potential advantages over models with two horizontal dimensions

- higher resolutions possible
- better suited for process studies due to lower complexity

The Parallel Ice Sheet Model (PISM, www.pism-docs.org) is a model with two horizontal dimensions

- Flow-line model capabilities were added by periodizing the cross-flow direction
- Tools were added to facilitate flow-line modeling

Model description

The Parallel Ice Sheet Model project provides an open source, fully-parallel, high-resolution ice sheet model.

It has these features:

- a hierarchy of available stress balances, including shallow ice and shelf approximations, a hybrid of these [Bueler and Brown, 2009]
- verification and validation tools
- a polythermal, enthalpy-based conservation of energy scheme
- extensible coupling to atmospheric and ocean models
- complete documentation for users and developers

From the software point of view, PISM is a C++ program which

- uses PETSc for parallel numerics and MPI for interprocess communication
- reads and writes NetCDF files
- automatically converts units by using UDUNITS
- generates CF 1.4-compliant NetCDF files

PISM works with a range of pre- and post-processing tools

Using NetCDF and following CF Conventions means that PISM users have many data analysis, pre- and post-processing and visualization tools to choose from:

- *NetCDF Operators (NCO)*
- *Climate Data Operators (CDO)*
- *Unidata IDV*
- plotting libraries such as
  - *PyNGL*
  - *Matplotlib Basemap Toolkit*
  - *Panoply*
  - *GMT*

and many others that can read netCDF.

Flow Line Application Mode

`flowline.py` is a python script to convert input and output:

1. create a input file `myflowline_input.nc` in netCDF format containing only (t,z,x) dimensions
2. run `flowline.py -e myflowline_input.nc my3d_input.nc`, the script will expand dimensions to (t,z,y,x)
3. run PISM with your favorite settings
4. run `flowline.py -c my3d_output.nc myflowline_output.nc` to collapse dimensions back to (t,z,x)

Storglaciären

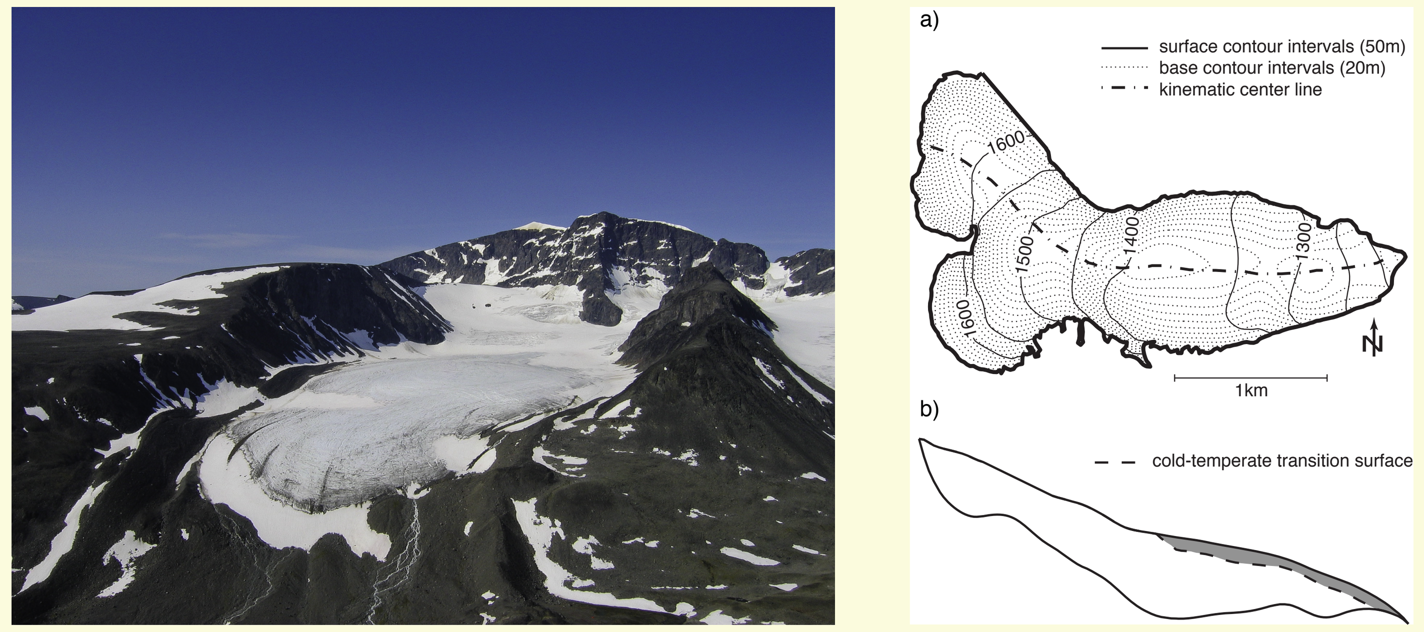

Figure 1: Left: Storglaciären, northern Sweden. July 2004. Photo courtesy of R. Hock. Right: Map with kinematic center line (upper panel) and longitudinal cross-section with observed thermal structure. Grey indicates cold ice.

Storglaciären is a

- small valley glacier in northern Sweden (Fig. 1, left)
- is a *Scandinvian-type* polythermal glacier: most of the ice is temperate except for a thin near-surface layer in the ablation zone (Fig. 1, right)

Model Setup and Parameters

- all simulations done along the flow-line shown in Fig. 1
- non-sliding shallow ice approximation (SIA) and hybrid stress balance (BBA)

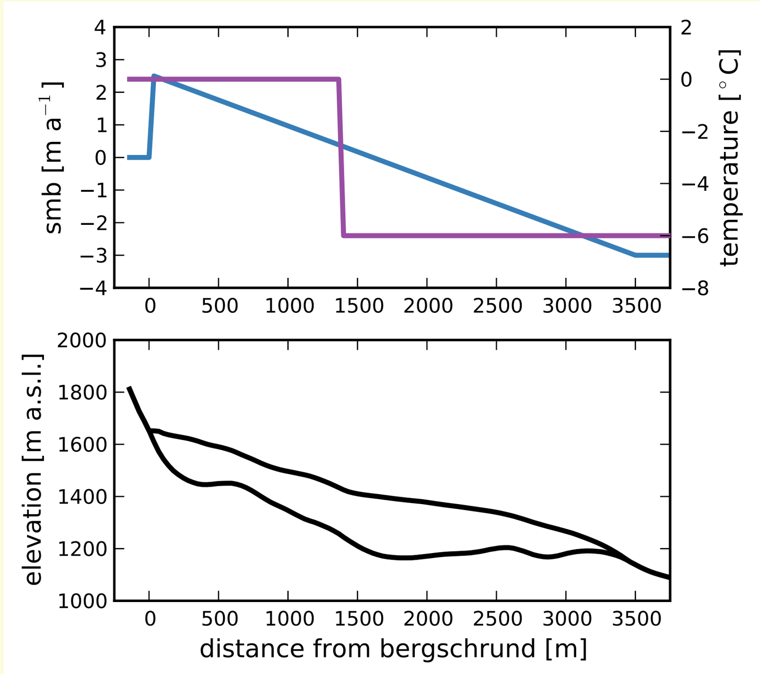

Figure 2: Upper panel: surface mass balance (blue line) and surface temperature (purple line). Lower panel: observed bedrock and upper ice surface elevation.

Variable	Name	Value	Unit
E	enhancement factor	0.3	
dx	horizontal grid spacing	5	m
dz	vertical grid spacing	1.5	m
ϕ	till friction angle	20	°
q	pseudo-plasticity exponent	0.75	
q_{geo}	geothermal flux	42	mW m^{2}
u_0	threshold speed	10	m a^{-1}

Table 1: Model parameters

- Surface boundary conditions are shown in Fig. 2
- geothermal flux
- basal velocity either zero (SIA) or determined by the sliding law below (BBA)
  - The basal shear stress τ_b is assumed to be proportional to a power of the sliding velocity:

$$\vec{\tau}_b = -(\tan\phi)(\rho g H - p_w)\frac{\vec{u}_b}{|\vec{u}_b|^{(1-q)}u_0^q} = \tau_c \frac{\vec{u}_b}{|\vec{u}_b|^{(1-q)}u_0^q}. \quad (1)$$

where H is the ice thickness, $\rho g H$ is the overburden pressure, p_w is the basal water pressure and τ_c is called the "yield stress".

Results

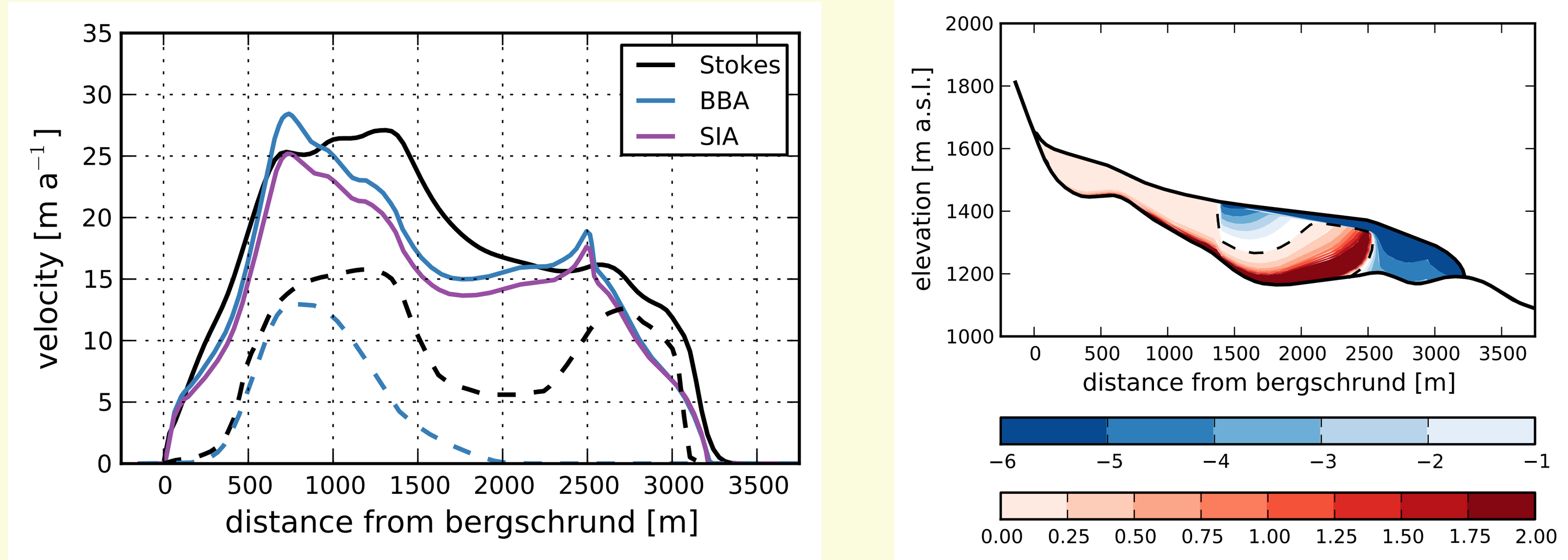

Figure 3: Simulated velocities (left) and thermal structure (right). Red colors indicate liquid water fraction, blue colors are temperature. Dashed line is the cold-temperate transition surface.

- Fig. 3 (left) shows modeled horizontal velocities at the surface (SIA and BBA) and at the base (BBA only)
- For comparison, a full Stokes solution from Aschwanden and Blatter [2009] is shown, using prescribed basal velocities
- **boundary conditions for full Stokes and SIA/BBA were not excatly the same, so comparability is very limited!**
- Both SIA and BBA capture the main flow features
- Fig. 3 (right) shows the simulated thermal structure. The polythermal conservation of energy scheme is clearly able to produce a Scandinavian-type thermal structure

Summary

- **flow-line capabilities have been added to PISM**
- **PISM simulates Scandinavian-type polythermal glaciers**

References

A. Aschwanden and H. Blatter. Mathematical modeling and numerical simulation of polythermal glaciers. *J. Geophys. Res.*, 114, 2009. F01027, doi:10.1029/2008JF001028.

E. Bueler and J. Brown. Shallow shelf approximation as a "sliding law" in a thermodynamically coupled ice sheet model. *J. Geophys. Res.*, 114, 2009. F03008, doi:10.1029/2008JF001179.

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PISM Support

Visit `www.pism-docs.org` and e-mail `help@pism-docs.org` if you have questions about PISM.

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