Initial Files for PISM runs and model spinup

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1 Bedrock and ice topography

The bedrock and ice topography are taken from the BedMachine data set v5.5 (July 2022) [1].

2 Geothermal heat flux

The geothermal heat fluxes are taken from the database [2], see references within for references to the individual data sets. Note that in the case of the Colgan dataset, the version without the NEGIS anomaly is used.

2.1 Mean geothermal heat flux

In addition to the individual geothermal heat flux map from [2], a mean geothermal heat field is provided as well, produced as a simple mean of the individual fields, following [3, 4]

3 Scripts for making PISM-compatible initial files

A number of scripts are used to convert the various data sets to versions compatible for PISM.

3.1 SeaRISE data

First, the SeaRISE data set is treated in order to convert the units of precipitation and surface mass balance, stripping off unused variables and changing variable names to suit PISM. Two versions of this script exist, one with only the conversions and one where time bounds are added to the file:

/home/syhsv/Projects/PISMInit/preprocess_local.sh
/home/syhsv/Projects/PISMInit/preprocess_localWithTimeBounds.sh

Output files without time bounds:

/mnt/data/syhsv/Data/PISMIn/SeaRISE/SeaRISEPISM/pism_Greenland_5km_v1.1.nc (Topography, present day climate, no time bounds)
/mnt/data/syhsv/Data/PISMIn/SeaRISE/SeaRISEPISM/pism_dT.nc (Temperature time series, from -125.000 years to present day, no time bounds)
/mnt/data/syhsv/Data/PISMIn/SeaRISE/SeaRISEPISM/pism_dSL.nc (Sea level time series, from -125.000 years to present day, no time bounds)

Output files with time bounds:
/mnt/data/syhsv/Data/PISMIn/SeaRISE/SeaRISEPISMWithBounds/pism_Greenland_5km_v1.1.nc (Topography, present day climate, with time bounds)
/mnt/data/syhsv/Data/PISMIn/SeaRISE/SeaRISEPISMWithBounds/pism_dT.nc (Temperature time series, from -125.000 years to present day, with time bounds)
/mnt/data/syhsv/Data/PISMIn/SeaRISE/SeaRISEPISMWithBounds/pism_dSL.nc (Sea level time series, from -125.000 years to present day, with time bounds)

The time bounds are needed by PISM when using the fields to force runs: the time bounds are interpreted as the left and right end points of the time interval where a particular value of the forcing field is applied, see the PISM manual [5] section 4.1 'Adding time-dependent forcing', particularly subsection 4.15 'Adding time bounds' on how to make time bounds based on the time variable in an input data file.

3.2 BedMachine and geothermal heat flux data

Next, the processed SeaRISE data is stripped of its bedrock and ice sheet topography as well as the geothermal heat flux field. New versions of these fields are pulled in from the BedMachine data set and the various geothermal heat flux data sets from [2] and all fields are interpolated on to a 1×1 km grid. In some cases, outer areas of the domains are not the same, and in this case areas with NaNs are filled with dummy values corresponding to a reasonable mean value. -This is far away from the coast so it should not have too much of an effect on the ice sheet. There is one script for each version of the geothermal heat flux:

/home/syhsv/Projects/PISMInit/Initfile_BHFArtemieva.sh
/home/syhsv/Projects/PISMInit/Initfile_BHFColgan.sh
/home/syhsv/Projects/PISMInit/Initfile_BHFGreve.sh
/home/syhsv/Projects/PISMInit/Initfile_BHFLucazeau.sh
/home/syhsv/Projects/PISMInit/Initfile_BHFMartos.sh
/home/syhsv/Projects/PISMInit/Initfile_BHFRezvanbehbahani.sh
/home/syhsv/Projects/PISMInit/Initfile_BHFMeanField.sh

The last script is the script that produces the file with the mean geothermal heat flux field.
Two versions of output files exist; one where outer edges of mismatching domains are kept as is and one where these areas are filled with dummy values:

*/mnt/data/syhsv/Data/PISMIn/BedMachine/BedMachinePISM/BasalHeatflux/***BHFName***/pism-Greenland_BedMachine_***BHFName***_1km.nc*
*/mnt/data/syhsv/Data/PISMIn/BedMachine/BedMachinePISM/BasalHeatflux/***BHFName***/pism-Greenland_BedMachine_***BHFName***_1km-filled.nc*

Here, **BHFName** indicates one of the possible geothermal heat flux fields (Artemieva, Colgan, Greve, Lucazeau, Martos, Rezvanbehbahani, MeanBHF) and the files with the extension '*filled*' have been filled with dummy values on the rim.

3.2.1 Smoothing the bedrock

Sometimes, too steep gradients in the bedrock may pose a numerical problem for PISM, usually resulting in an error message regarding the diffusivity of the SIA stress balance (variable *stress_balance.sia.max_diffusivity*) exceeding a maximum threshold value. It is possible to use versions of the initial files, that have been smoothed locally in areas where the gradient of the bed topography is particularly large. This is done with the script

/home/syhsv/PPP/BedTopo/LocalSmoothing_Bedrock.py

This script takes calculates the gradient of the bedrock topography and locates areas where the size of the gradient exceeds a certain threshold defined as a certain percentage (currently 50%, but this may be changed by adjusting the value of the parameter 'limit' in the script) of the maximum value of the gradient and replaces the topography in these points with a smoothed value based on linear interpolation. The corresponding output files are

*/mnt/data/syhsv/Data/PISMIn/BedMachine/BedMachinePISM/BasalHeatflux/***BHFName***/pism-Greenland_BedMachine_***BHFName***_1km-filled-smoothed.nc*

where **BHFName** indicates one of the possible geothermal heat flux fields (Artemieva, Colgan, Greve, Lucazeau, Martos, Rezvanbehbahani, MeanBHF).

3.2.2 Adding upper and lower boundaries to the geothermal heat flux field

In order to be able to do simulations examining the sensitivity of the ice sheet to changes in geothermal heat flux in PISM, basic forcing files are made with a constant value added to or subtracted from the geothermal heat flux field. Currently, the value of this constant value is based on the mean value of the RMSE of each of the geothermal heat flux datasets. This mean value is 18.67 W/m^2, so a value of 20 W/m^2 has been chosen as the constant value to be added or subtracted to the geothermal heat flux fields. In the case where the value is subtracted, an extra condition is added ensuring that the geothermal heat flux will never be negative: In case the difference between the geothermal heat flux and the constant of 20 W/m^2 is negative, the value is set to 0. This is done for all the available versions of the geothermal heat flux in a single script:

/home/syhsv/Projects/PISMInit/Add_BHF_Bounds.sh

and the corresponding output files are
*/mnt/data/syhsv/Data/PISMIn/BedMachine/BedMachinePISM/BasalHeatflux/***BHFName***/pism-Greenland_BedMachine_***BHFName***_1km-filled-smoothed_upper.nc*
*/mnt/data/syhsv/Data/PISMIn/BedMachine/BedMachinePISM/BasalHeatflux/***BHFName***/pism-Greenland_BedMachine_***BHFName***_1km-filled-smoothed_lower.nc*

where 'upper' and 'lower' indicates upper or lower limits of the envelope.

4 PISM physics and calving choices

PISM is very versatile and a number of different processes and parameters may be set when preparing a run.

4.1 Physics choices

The basic PISM runs described follow the parameter settings as described in [6] with a few add-ons such as additional lateral drag in narrow outlet systems (parameter *basal.resistance.beta_lateral_margin*. The physics settings are given here:

PHYSICS='-bed_def lc -stress_balance ssa+sia -pseudo_plastic -pseudo_plastic_q 0.6 -stress_balance.sia.Glen_exponent 3 -stress_balance.sia_enhancement_factor 1 -stress_balance.sia.max_diffusivity 10000 -stress_balance.ssa.Glen_exponent 3.25 -stress_balance.ssa.enhancement_factor 1 -basal.resistance.beta_lateral_margin -yield_stress mohr_coulomb -topg_to_phi 5,40,-1000,700'

The somewhat artificial setting of the parameter*stress_balance.sia.max_diffusivity* to the high value of 10000 is in order to avoid too many stops in model runs due to this parameter exceeding its threshold value, which is usually related to challenges of the numerics in areas with very steep gradients in topography.

4.2 Calving

Modelling calving processes in the fjord systems characteristic of Greenland is challenging. The basic PISM runs uses the following settings for calving:

CALVING='-cfbc -kill_icebergs -part_grid -subgr -calving vonmises_calving,thickness_calving -calving.thickness_calving -calving_threshold 150'

These settings apply von Mises calving as well as calving based on a critical value of the thickness of the floating ice based on the experience that calving fronts are rarely thin, but are usually higher than 150-250 m. Here, all floating ice thinner than a threshold value of 150 m are calved off. Also, stress boundary conditions along the ice calving front is applied, free-floating icebergs are removed and sub-grid cell advance and retreat of the ice front is allowed.

5 Constant climate runs with present-day conditions

A number of runs with constant climate are done at increasingly higher resolution to investigate the influence of resolution on dynamics. Present day mean climate forcings (temperature, precipitation and surface mass balance) are taken from the SeaRISE dataset, see [7] and references therein. A description of how the SeaRISE data has been processed to produce forcing files is given in sec.(3.1). An initial bootstrapping run is made based on the basic initial file followed by a series of regridding runs going to increasingly higher resolutions:

1. Bootstrapping run for 20.000 years at 20 km resolution
2. Regrid to 10 km and run for 10.000 years
3. Regrid to 5 km and run for 5.000 years
4. Regrid to 2 km and run for 500 years

The forcing mechanism for these runs is

FORCING='-surface given -surface_given_file '${startfile}'

where 'startfile' is the name of the basic initial file with the present-day forcing fields. This regridding sequence is done for all available geothermal heat flux fields, including the mean field, using the following scripts located in the directory:

*/home/syhsv/Projects/Spinup/BasalHeatFlux/***BHFName**/

*BedMachineBootstrap_BHF***BHFName***.sh*
*run_BedMachineBootstrap_BHF***BHFName***.sh*
Regrid20to10.sh
run_Regrid20to10.sh
Regrid10to5.sh
run_Regrid10to5.sh
Regrid5to2.sh
run_Regrid5to2.sh

The 'run_'-scripts are basic scripts that call the corresponding PISM script itself, launches it and open a log file. **BHFName** indicates the particular set of geothermal heat flux data used for that particular run.

5.1 Sensitivity to variations in the geothermal heat flux field

In order to have an estimate of the sensitivity of the ice sheet to changes in the geothermal heat flux field, the runs with the different geothermal heat flux fields are repeated, but with a constant heat flux either added or subtracted to the geothermal heat flux field as described in sec.(3.2.2). These runs all follow the same run sequence as described above (sec.(5)) using the following scripts located in the directory:

*/home/syhsv/Projects/Spinup/BedMachine/BasalHeatFlux/***BHFName***/*

*BedMachineBootstrap_BHF***BHFName***_upper.sh*
*run_BedMachineBootstrap_BHF***BHFName***_upper.sh*
Regrid20to10_upper.sh
run_Regrid20to10_upper.sh
Regrid10to5_upper.sh
run_Regrid10to5_upper.sh
Regrid5to2_upper.sh
run_Regrid5to2_upper.sh

*BedMachineBootstrap_BHF***BHFName***_lower.sh*
*run_BedMachineBootstrap_BHF***BHFName***_lower.sh*
Regrid20to10_lower.sh
run_Regrid20to10_lower.sh
Regrid10to5_lower.sh
run_Regrid10to5_lower.sh
Regrid5to2_lower.sh
run_Regrid5to2_lower.sh

Here, *_upper* and *_lower* indicates if the run is using the upper or lower limit geothermal heat flux fields and **BHFName** indicates the choice of geothermal heat flux field.

5.2 Output - Constant climate runs with present-day conditions

The output files for the runs described in sec.(5) and sec.(5.1) are located in the directory

*/mnt/data/syhsv/Data/PISMOut/Spinups/BedMachine/BasalHeatFlux/***BHFName**

for runs with the various geothermal heat flux fields (as indicated by **BHFName**).
The output files follow this naming convention:

- Runs with 20 km grid resolution for 20.000 years
  - Runs with regular geothermal heat flux field
    - *g20km_20ka_BedMachine_***BHFNAME***.nc*

        - ex_g20km_20ka_BedMachine_**BHFName**.nc
        - ts_g20km_20ka_BedMachine_**BHFName**.nc
    - Runs with upper limit geothermal heat flux field
        - g20km_20ka_BedMachine_**BHFNAME**_upper.nc
        - ex_g20km_20ka_BedMachine_**BHFName**_upper.nc
        - ts_g20km_20ka_BedMachine_**BHFName**_upper.nc
    - Runs with lower limit geothermal heat flux field
        - g20km_20ka_BedMachine_**BHFNAME**_lower.nc
        - ex_g20km_20ka_BedMachine_**BHFName**_lower.nc
        - ts_g20km_20ka_BedMachine_**BHFName**_lower.nc

- Runs with 10 km grid resolution for 10.000 years
    - Runs with regular geothermal heat flux field
        - g10km_10ka_BedMachine_**BHFNAME**.nc
        - ex_g10km_10ka_BedMachine_**BHFName**.nc
        - ts_g10km_10ka_BedMachine_**BHFName**.nc
    - Runs with upper limit geothermal heat flux field
        - g10km_10ka_BedMachine_**BHFNAME**_upper.nc
        - ex_g10km_10ka_BedMachine_**BHFName**_upper.nc
        - ts_g10km_10ka_BedMachine_**BHFName**_upper.nc
    - Runs with lower limit geothermal heat flux field
        - g10km_10ka_BedMachine_**BHFNAME**_lower.nc
        - ex_g10km_10ka_BedMachine_**BHFName**_lower.nc
        - ts_g10km_10ka_BedMachine_**BHFName**_lower.nc

- Runs with 5 km grid resolution for 5.000 years
    - Runs with regular geothermal heat flux field
        - g5km_5ka_BedMachine_**BHFNAME**.nc
        - ex_g5km_5ka_BedMachine_**BHFName**.nc
        - ts_g5km_5ka_BedMachine_**BHFName**.nc
    - Runs with upper limit geothermal heat flux field
        - g5km_5ka_BedMachine_**BHFNAME**_upper.nc
        - ex_g5km_5ka_BedMachine_**BHFName**_upper.nc
        - ts_g5km_5ka_BedMachine_**BHFName**_upper.nc
    - Runs with lower limit geothermal heat flux field
        - g5km_5ka_BedMachine_**BHFNAME**_lower.nc
        - ex_g5km_5ka_BedMachine_**BHFName**_lower.nc

- ∗ *ts_g5km_5ka_BedMachine_***BHFName***_lower.nc*

- Runs with 2 km grid resolution for 500 years
  - Runs with regular geothermal heat flux field
    - ∗ *g2km_500a_BedMachine_***BHFNAME***.nc*
    - ∗ *ex_g2km_500ka_BedMachine_***BHFName***.nc*
    - ∗ *ts_g2km_500a_BedMachine_***BHFName***.nc*
  - Runs with upper limit geothermal heat flux field
    - ∗ *g2km_500a_BedMachine_***BHFNAME***_upper.nc*
    - ∗ *ex_g2km_500a_BedMachine_***BHFName***_upper.nc*
    - ∗ *ts_g2km_500a_BedMachine_***BHFName***_upper.nc*
  - Runs with lower limit geothermal heat flux field
    - ∗ *g2km_500a_BedMachine_***BHFNAME***_lower.nc*
    - ∗ *ex_g2km_500a_BedMachine_***BHFName***_lower.nc*
    - ∗ *ts_g2km_500a_BedMachine_***BHFName***_lower.nc*

6 Glacial cycle runs

The glacial cycle runs is a series of runs with time-varying forcing corresponding to a glacial cycle. Glacial cycle climate forcings are taken from the SeaRISE dataset, see [7] and references therein. A description of how the SeaRISE data has been processed to produce forcing files is given in sec.(3.1). The runs start at a coarse 20 km resolution and, as time approaches present day, regrid to increasingly higher resolutions, where the initial 20 km runs are based on the outcome of the 20.000 years bootstrapping run at 20 km resolution described in sec.(5):

1. Bootstrapping run for 20.000 years at 20 km resolution with constant climate
2. Run from -125.000 years to -25.000 years (100.000 years) at 20 km resolution
3. Run from -25.000 years to -5.000 years (20.000 years) at 10 km resolution
4. Run from -5.000 years to -500 years (4.500 years) at 5 km resolution
5. Run from -500 years to present (500 years) at 2 km resolution

The run scripts for these runs are located in

*/home/syhsv/Projects/Spinup/BedMachine/BasalHeatFlux/***BHFNAME***/*

where **BHFName** refers to the choice of geothermal heat flux field. The run scripts have the following names

- 100.000 year run on 20 km resolution
  - GlaCyc_20km_**BHFName**.sh
  - run_GlaCyc_20km_**BHFName**.sh
- 20.000 year run on 10 km resolution
  - GlaCyc_10km_**BHFName**.sh
  - run_GlaCyc_10km_**BHFName**.sh
- 4.500 year run on 5 km resolution
  - GlaCyc_5km_**BHFName**.sh
  - run_GlaCyc_5km_**BHFName**.sh
- 500 year run on 2 km resolution
  - GlaCyc_2km_**BHFName**.sh
  - run_GlaCyc_2km_**BHFName**.sh

The model choices are similar to the constant climate settings, see sec.(4), only the calving has been switched off since it (for reasons yet to be investigated) made the runs very slow.
The output from these runs can be found in

*/mnt/data/syhsv/Data/PISMOut/Spinups/BedMachine/BasalHeatFlux/***BHFName***/GlacialCycle/*

The output files adhere to the following naming convention:

- 100.000 year run on 20 km resolution
  - g20km_GlaCy_100ka_BedMachine_**BHFName**.nc
  - ts_g20km_GlaCy_100ka_BedMachine_**BHFName**.nc
  - ex_g20km_GlaCy_100ka_BedMachine_**BHFName**.nc
- 20.000 year run on 10 km resolution
  - g10km_GlaCy_20ka_BedMachine_**BHFName**.nc
  - ts_g10km_GlaCy_20ka_BedMachine_**BHFName**.nc
  - ex_g10km_GlaCy_20ka_BedMachine_**BHFName**.nc
- 4.500 year run on 5 km resolution
  - g5km_GlaCy_4500a_BedMachine_**BHFName**.nc
  - ts_g5km_GlaCy_4500a_BedMachine_**BHFName**.nc
  - ex_g5km_GlaCy_4500a_BedMachine_**BHFName**.nc

- 500 year run on 2 km resolution
  - g2km_GlaCy_500a_BedMachine_**BHFName**.nc
  - ts_g2km_GlaCy_500a_BedMachine_**BHFName**.nc
  - ex_g2km_GlaCy_500a_BedMachine_**BHFName**.nc

where **BHFName** indicates the chosen geothermal heat flux data set. No sensitivity runs are done for the glacial cycle as the constant climate runs already gave an impression of the sensitivity to changes in geothermal heat flux.

References

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