

SICOPOLIS V5-dev

– Quick Start Manual –

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1 Requirements

- Unix-like system (e.g., Linux).
- Fortran compiler.
So far, the Intel and GNU Fortran compilers are supported. Make sure that the environment variable FC is set to either ifort (Intel) or gfortran (GNU). If you wish to use a different compiler, please contact <help@sicopolis.net>.
- Optional: GNU Autotools (automake, autoheader, aclocal, autoconf, make).
- SICOPOLIS supports output either in native binary or in NetCDF format (see Sect. 6). For the latter (recommended), you need an installation of NetCDF version 3.6.x or newer (<http://www.unidata.ucar.edu/software/netcdf/>).
- For the shallow-shelf/shelfy-stream solver, a recent version (1.4.43 or newer) of the Library of Iterative Solvers for Linear Systems (Lis) is required (<http://www.ssisc.org/lis/>).

2 Download

- **Using subversion**

The subversion repository of SICOPOLIS is kindly hosted by the FusionForge system AWIForge of the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven, Germany (front page: <https://swrepo1.awi.de/projects/sicopolis/>).

Check out the latest revision (“bleeding edge”) from the subversion repository:

```
svn checkout --username anonsvn --password anonsvn \  
https://swrepo1.awi.de/svn/sicopolis/trunk sicopolis  
(or username/password from your own AWIForge account)
```

Alternatively, check out any previous revision no. REVNUM
(changelog: <http://tinyurl.com/commit-logs-sico-trunk/>):

```
svn checkout --username anonsvn --password anonsvn -r REVNUM \  
https://swrepo1.awi.de/svn/sicopolis/trunk sicopolis  
(or username/password from your own AWIForge account)
```

Either way, you should then have a new directory “sicopolis” that contains the entire program package.

3 Initial configuration

3.1 First step

Go to the new directory “sicopolis” and execute the bash script `copy_templates.sh`:

```
./copy_templates.sh
```

3.2 Manual configuration [recommended]

1. Locate the file `sico_configs.sh` in the directory `sicopolis/runs`, and open it with a text editor.
2. Set the flags `NETCDF_FLAG`, `LIS_FLAG`, `OPENMP_FLAG` and `LARGE_DATA_FLAG` according to your needs.

Pre-selected is `NETCDF_FLAG="true"` (with NetCDF) and the rest “false”.

If you wish to create output in native binary format rather than in NetCDF format, set `NETCDF_FLAG` to “false”. For simulations with shallow-shelf dynamics (for floating ice) or hybrid shallow-ice–shelfy-stream dynamics (for grounded ice), `LIS_FLAG` and `OPENMP_FLAG` must both be set to “true”. For high-resolution simulations (e.g., Greenland/5 km or Antarctica/10 km), `LARGE_DATA_FLAG` must be set to “true”.

3. If `NETCDF_FLAG="true"`, set `NETCDFHOME` to the correct path of your NetCDF installation.

If `LIS_FLAG="true"`, set `LISHOME` to the correct path of your Lis installation.

4. Depending on your system, some additional settings might have to be added in `sico_configs.sh` (`module load` commands for dynamic loading etc.).

3.3 Building with GNU Autotools

As an alternative to the manual configuration described in Section 3.2, SICOPOLIS can also be built with the GNU Autotools. The configuration file `sico_configs.sh` can then be ignored. Instead, it is required to execute the script `autogen.sh`:

```
./autogen.sh [ --with-netcdf=/my_netcdf_path \  
               --with-lis=/my_lis_path \  
               --enable-openmp=yes \  
               --enable-large_data=yes ]
```

The four options have the same function as the flags discussed in Section 3.2. If the NetCDF library is linked, set `/my_netcdf_path` to the correct path of your NetCDF installation. If the Lis library is linked, set `/my_lis_path` to the correct path of your Lis installation.

4 Files and directories in “sicopolis”

- **runs:**

Configuration file `sico_configs.sh`

(only needed for manual configuration; see Section 3.2).

Shell script (bash) `sico.sh` for running a single simulation.

Shell scripts (bash) `multi_sico_1.sh` and `multi_sico_2.sh` for running multiple simulations by repeated calls of `sico.sh`.

Subdirectory **headers**: specification files `sico_specs_run_name.h` (*run_name*: name of run).

- File included for run `v5_emtp2sge25_expA`
 - EISMINT Phase 2 Simplified Geometry Experiment A, resolution 25 km, $t = 0 \dots 200$ ka (Payne et al. 2000).
The thermodynamics solver for this run is the one-layer melting-CTS enthalpy scheme (ENTM), while all other runs employ the polythermal two-layer scheme (POLY) (Greve and Blatter 2016).
- File included for run `v5_grl20_ss25ka`
 - Greenland ice sheet, resolution 20 km, short steady-state run ($t = 0 \dots 25$ ka) for modern climate conditions (unpublished).
- File included for run `v5_ant40_ss25ka`
 - Antarctic ice sheet without ice shelves, resolution 40 km, short steady-state run ($t = 0 \dots 25$ ka) for modern climate conditions (unpublished).
- File included for run `v5_grl20_b2_paleo21`
 - Greenland ice sheet, resolution 20 km, $t = -140 \dots 0$ ka, basal sliding ramped up during the first 5 ka [modified, low-resolution version of the spin-up for ISMIP6 InitMIP; Greve et al. (2017)].
- Files included for runs `v5_grl10_b2_paleo21` and `v5_grl10_b2_future21_ctrl/..._asmb`
 - Greenland ice sheet, resolution 10 km, $t = -9 \dots 0$ ka for the paleo run, $t = 0 \dots 100$ a for the future runs [10-km version of the spin-up and the schematic future climate runs for ISMIP6 InitMIP; Greve et al. (2017)].

- Files included for runs `v5_ant64_b2_spinup09_init100a`,
`v5_ant64_b2_spinup09_fixtopo`, `v5_ant64_b2_spinup09` and
`v5_ant64_b2_future09_ctrl`
 - Antarctic ice sheet with hybrid shallow-ice–shelvy-stream dynamics (Bernales et al. 2017) and ice shelves, resolution 64 km,
 $t = -140.1 \dots -140.0$ ka for the init run without basal sliding (..._init100a),
 $t = -140 \dots 0$ ka for the run with almost fixed topography (..._fixtopo),
basal sliding ramped up during the first 5 ka,
 $t = -0.5 \dots 0$ ka for the final, freely-evolving-topography part of the
spin-up (..._spinup09),
 $t = 0 \dots 100$ a for the constant-climate control run (..._future09_ctrl)
[64-km version of the spin-up and the constant-climate control run for
ISMIP6 InitMIP; Greve and Galton-Fenzi (pers. comm. 2017)].
- Files included for runs `v5_asf2_steady` and `v5_asf2_surge`
 - Austfonna, resolution 2 km, $t = 0 \dots 10$ ka
[similar to Dunse et al.’s (2011) Exp. 2 (steady fast flow) and
Exp. 5 (surging-type flow), respectively].
- Files included for runs `v5_nmars10_steady` and `v5_smars10_steady`
 - North-/south-polar cap of Mars, resolution 10 km, $t = -10 \text{ Ma} \dots 0$
[steady-state runs by Greve (2007)].
- File included for run `v5_nhem80_nt012_new`
 - northern hemisphere, resolution 80 km, $t = -250 \dots 0$ ka
[similar to run nt012 by Greve et al. (1999)].
- File included for run `v5_heino50_st`
 - ISMIP HEINO standard run ST,
resolution 50 km, $t = 0 \dots 200$ ka (Calov et al. 2010).

- **src:**

Directory that contains the main program file `sicopolis.F90`.

- Subdirectory **subroutines/general**: general subroutines, for any modelled domain.
- Subdirectory **subroutines/ant**: subroutines specific for the Antarctic ice sheet.
- Subdirectory **subroutines/emtp2sge**: subroutines specific for the EISMINT Phase 2 Simplified Geometry Experiments.
- Subdirectory **subroutines/grl**: subroutines specific for the Greenland ice sheet.

- Accordingly subdirectories subroutines/asf, nhem, scand, tibet, nmars and smars for Austfonna, the northern hemisphere, Scandinavia, Tibet and the north and south polar caps of Mars, respectively.
- Subdirectory **subroutines/xyz**: see Appendix A.

- **sico_in:**

Directory that contains input data files for SICOPOLIS.

- Subdirectory **general**: general input files, for any modelled domain.
- Subdirectory **ant**: input files specific for the Antarctic ice sheet.
- Subdirectory **empt2sge**: input files specific for the EISMINT Phase 2 Simplified Geometry Experiments.
- Subdirectory **grl**: input files specific for the Greenland ice sheet.
- Accordingly subdirectories asf, nhem, scand, tibet, nmars and smars for Austfonna, the northern hemisphere, Scandinavia, Tibet and the north and south polar caps of Mars, respectively.
- Subdirectory **xyz**: see Appendix A.

- **sico_out:**

Empty directory into which output files of SICOPOLIS simulations are written.

- **docu:**

Directory that contains some documentation.

- Subdirectory **quick_start**:
 \LaTeX source for this manual (PDF must be built with make).
- Subdirectory **doxygen**: documentation to be created by Doxygen (optional, see doxygen-config/README.txt).
 - * html/index.html \longrightarrow Source code browser.
 - * latex/refman.pdf \longrightarrow Reference manual.

- **tools:**

See Sects. 7 and 9.

- **license:**

Directory that contains a copy of the GNU General Public License (version 3).

5 How to run a simulation

1. It is recommended to run SICOPOLIS with output in NetCDF format. If you wish to create output in native binary format instead, set NETCDF to 1 (rather than 2) in all specification files `sico_specs_run_name.h`.

2. In order to run simulation `v5_grl20_ss25ka`, use the script `sico.sh`. The command is

```
(./sico.sh [-u] -m v5_grl20_ss25ka) >out_001.dat 2>&1 &
```

(from directory `sicopolis/runs`, bash required). Accordingly for the other simulations. The option `-u` is only required if SICOPOLIS was built with the GNU Autotools. If it was configured manually, omit it. For further options, try `./sico.sh -h`.

3. Alternatively, if you prefer to run all simulations consecutively, execute the script `multi_sico_1.sh`:

```
(./multi_sico_1.sh [-u]) >out_multi_100.dat 2>&1 &
```

Again, the option `-u` is only required if SICOPOLIS was built with the GNU Autotools. For further options, try `./multi_sico_1.sh -h`.

Computing times

The approximate computing times for the simulations, run with the Intel Fortran Compiler 17.0.1 for Linux (optimization options `-xHOST -O3 -no-prec-div`) on a 2×14 -Core Intel Xeon E5-2690 v4 (2.6 GHz) PC under openSUSE Leap 42.2, are listed in Table 1 (Appendix B).

6 Output files

Output files are written by default to the directory `sicopolis/sico_out/run_name` (this can be changed with the `-d` option). Four types are produced:

- **run_name.log:**

ASCII file that lists the main specifications of simulation `run_name`.

- **run_name.ser:**

Time-series file (ASCII) that contains global parameters:

- Time, `t`
- Surface temperature anomaly, `D_Ts`, or glacial index, `glac_ind` (forcing)
- Sea level, `z_sl` (forcing)

- Total ice volume, V
- Volume of grounded ice, V_g
- Volume of floating ice, V_f
- Total ice area, A
- Area of grounded ice, A_g
- Area of floating ice, A_f
- Ice volume above flotation in sea level equivalent, V_{sle}
- Volume of temperate ice, V_t
- Area of temperate-based grounded ice, A_t
- Maximum ice thickness, H_{max}
- Maximum thickness of temperate ice, $H_{t,max}$
- Maximum surface elevation, $z_{s,max}$
- Maximum surface speed, $v_{s,max}$
- Maximum basal temperature (relative to pmp), $T_{bh,max}$

● **run_name.core:**

Time-series file (ASCII) that contains for selected locations xxx:

- Time, t
- Surface temperature anomaly, D_{Ts} , or glacial index, $glac_ind$ (forcing)
- Sea level, z_{sl} (forcing)
- Thickness, H_{xxx}
- Surface velocity, v_{xxx}
- Basal temperature, T_{xxx}

For the Greenland ice sheet, these data are written for seven locations:

GRIP (xxx=GR), GISP2 (xxx=G2), Dye 3 (xxx=D3), Camp Century (xxx=CC), NorthGRIP (xxx=NG), NEEM (xxx=NE), EastGRIP (xxx=EG).

For the Antarctic ice sheet, these data are written for six locations:

Vostok (xxx=Vo), Dome A (xxx=DA), Dome C (xxx=DC), Dome F (xxx=DF), Kohlen (xxx=Ko), Byrd (xxx=By).

- **run_name0001.nc/.erg, run_name0002.nc/.erg, ...:**

Complete set of fields (topography, velocity, temperature etc., written either in NetCDF (*.nc) or in native binary (*.erg) format; see subroutines `output_nc` and `output1`, respectively) for selected time slices defined in specifications file. For example, simulation `v5_grl20_ss25ka` produces three files `v5_grl20_ss25ka0001.nc`, `v5_grl20_ss25ka0002.nc` and `v5_grl20_ss25ka0003.nc`, which correspond to $t = 0, 10$ ka and 25 ka, respectively.

7 Plotting with SICOGRAPH

The output described in Sect. 6 can be visualized with any plotting tool at the user's preference. One possibility is to use SICOGRAPH, which is part of the SICOPOLIS package and based on the Generic Mapping Tools GMT (<http://gmt.soest.hawaii.edu/>).

7.1 Installation

1. If you do not have an installation of GMT version 4.x yet, download and install the latest version according to the instructions on the GMT web site.
2. SICOGRAPH is included in the subversion repository of SICOPOLIS. You'll find it in the directory `sicopolis/tools/sicograph`.

7.2 Producing plots

In order to plot the output of simulation `v5_grl20_ss25ka`, go to the directory `sicopolis/tools` and execute the script `tools.sh` interactively:

```
./tools.sh [-u] -p sicograph -m v5_grl20_ss25ka
```

(bash required; accordingly for the other simulations). The option `-u` is only required if SICOPOLIS was built with the GNU Autotools. If it was configured manually, omit it. For further options, try `./tools.sh -h`.

You'll get a menu that allows you to choose the type of plot you wish to produce. For example, try the option

```
(1) Ice-surface topography
```

and enter

```
Number of time-slice file (with leading zeros, 4 digits) > 0003
```

```
Time-slice file contains:
```

```
(0) only 2-d arrays, (1) full set of 2-d and 3-d arrays > 1
```

Plot (1) with or (2) without colour bar? > 1

Plot (1) with or (2) without contour labels? > 1

You will find the plot in the subdirectory `sicograph/gmt_scripts/plots` as file `v5_grl20_ss25ka0003_zs.eps` (in EPS format). As a second example, try

(41) Time series

and in the following sub-menu choose

(5) Total ice volume

This produces the file `v5_grl20_ss25ka_V_tot.eps` in the subdirectory `sicograph/gmt_scripts/plots`.

7.3 Manipulating plot appearance

For all types of plots, the files in the subdirectory `sicograph/parameter_files` control the limits and labels of the x - and y -axes. In addition, for the plan-view plots, the files in the subdirectory `sicograph/gmt_scripts/cpt` control the colour scales (`*.cpt`) and contour levels (`*.zzz`). If a file is missing, the corresponding parameters are computed automatically.

8 Plotting with MATLAB

NetCDF output from SICOPOLIS can be visualized by MATLAB, which has an extensive library for NetCDF files (<https://www.mathworks.com/help/matlab/ref/netcdf.html>). For instance, the following script plots the final surface topography of the Greenland simulation `v5_grl20_ss25ka` (credit: Mathieu Morlighem, University of California Irvine).

```
filename = 'v5_grl20_ss25ka0003.nc';
x = ncread(filename,'x');
y = ncread(filename,'y');
surf = ncread(filename,'zs');
surf = surf'; % Transposition (MATLAB is column-oriented)
% Display surface elevation
imagesc(x*1e-3,y*1e-3,surf); axis xy equal; caxis([0 3200]); colorbar
```

9 Some useful tools

In addition to SICOGRAPH, the directory sicopolis/tools contains some further useful tools.

9.1 Program `make_ismip_output`

Generating ISMIP output (see <http://tinyurl.com/clic-ismip6>) from the NetCDF time-slice files produced by SICOPOLIS (see Sect. 6). For simulation *run_name*, to be executed by

```
./tools.sh [-u] -p make_ismip_output -m run_name
```

The option `-u` is only required if SICOPOLIS was built with the GNU Autotools. If it was configured manually, omit it. For further options, try `./tools.sh -h`.

9.2 Program `resolution_doubler`

Doubling the horizontal resolution of a NetCDF time-slice output file produced by SICOPOLIS (see Sect. 6). For simulation *run_name*, to be executed by

```
./tools.sh [-u] -p resolution_doubler -m run_name
```

Again, the option `-u` is only required if SICOPOLIS was built with the GNU Autotools. For further options, try `./tools.sh -h`.

For example, run `v5_grl10_b2_paleo21` (10 km resolution) requires the resolution-doubled output of run `v5_grl20_b2_paleo21` (20 km resolution) for $t = -9$ ka as initial condition. In order to create it, execute the resolution doubler for run `v5_grl20_b2_paleo21` (i.e., with the option `-m v5_grl20_b2_paleo21`) and enter

```
Number of time-slice file (with leading zeros, 4 digits) > 0004
```

This will convert the original time-slice file `v5_grl20_b2_paleo210004.nc` to the resolution-doubled file `v5_grl20_b2_paleo21_dbl.0004.nc` that serves as initial conditions for run `v5_grl10_b2_paleo21`.

A Domain XYZ

This framework allows creating new domains (Laurentide ice sheet, simple testing geometry etc.). The directory `sicopolis/src/subroutines/xyz`, which hosts the domain-specific subroutines, is by default empty. If you want to create a new domain, copy the subroutines from the most similar existing domain (northern hemisphere, EISMINT etc.), e.g.:

```
cp sicopolis/src/subroutines/nhem/*.F90 \  
   sicopolis/src/subroutines/xyz/
```

Then modify the routines according to your needs. Input files (topography etc.) must be placed in `sicopolis/sico_in/xyz` and specified in the run-specification header file `*.h` as usual. The domain must be defined by the domain code `'#define XYZ'` in the header file. If the new domain requires new global variables, they can be defined in the module `sicopolis/src/subroutines/xyz/sico_vars.F90`.

The subroutines for ISMIP HEINO are available in `sicopolis/src/subroutines/xyz/heino`, and the input files are in `sicopolis/sico_in/xyz`. If you copy the subroutines from `sicopolis/src/subroutines/xyz/heino` to `sicopolis/src/subroutines/xyz`, you can run ISMIP HEINO experiments (e.g., the run `v5_heino50.st` for which a header file is available).

B Table: Simulations and computing times

Run	Model time	Time step [†]	CPU time [‡]
v5_emtp2sge25_expA	200 ka	20 a	7.2 min
v5_grl20_ss25ka	25 ka	5 a	11.1 min
v5_ant40_ss25ka	25 ka	10 a	9.7 min
v5_grl20_b2_paleo21	140 ka	5 a	1.5 hrs
v5_grl10_b2_paleo21*	9 ka	1 a	1.8 hrs
v5_grl10_b2_future21_ctrl	100 a	1 a	1.7 min
v5_grl10_b2_future21_asmb	100 a	1 a	1.7 min
v5_ant64_b2_spinup09_init100a	100 a	2 / 10 a [†]	5.8 sec
v5_ant64_b2_spinup09_fixtopo	140 ka	5 / 10 a [†]	1.0 hrs
v5_ant64_b2_spinup09	500 a	2 / 10 a [†]	0.5 min
v5_ant64_b2_future09_ctrl	100 a	2 / 10 a [†]	7.0 sec

Table 1: Model times, time steps and computing (CPU) times for the EISMINT, Greenland and Antarctica simulations contained in the script `multi_sico_1.sh`, run with SICOPOLIS V5-dev (revision 1392) and the Intel Fortran Compiler 17.0.1 for Linux (optimization options `-xHOST -O3 -no-prec-div`) on a 2×14 -Core Intel Xeon E5-2690 v4 (2.6 GHz) PC under openSUSE Leap 42.3.

[†]: If one value is given, this is the common dynamic (velocity, ice thickness) and thermodynamic (temperature, water content, age) time step. If two values are given (marked by the dagger ([†]) symbol), the first one is the dynamic, the second one the thermodynamic time step.

[‡]: All runs were done on a single core only. The `v5_ant64_b2_XXX` runs that include ice shelves can be done on multiple cores using OpenMP for the SSA solver. However, at the employed, low resolution of 64 km the solver does not scale well, and the gain in wall clock time by using multiple cores is very small.

*: For this run, see the remark in Sect. 9.2 on the tool `resolution_doubler`.

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