ESM-SnowMIP reference site simulations

1. Introduction

ESM-SnowMIP is aimed at evaluating and improving the modelling of snow as part of the WCRP Grand Challenge “Melting Ice & Global Consequences”. Building on previous SnowMIP initiatives, ESM-SnowMIP complements the LS3MIP subproject of CMIP6 designed to evaluate the land surface modules of Earth System Models and to quantify land-related feedbacks. There are three types of simulations in ESM-SnowMIP, as described in the protocol at http://www.climate-cryosphere.org/media-gallery/1512-esmsnowmip-simulationprotocol:

- global coupled simulations with land-surface and ocean models coupled to atmospheric models, as in CMIP6
- global offline simulations with prescribed meteorological forcing for land points only, as in GSWP3
- plot-scale simulations with prescribed meteorological forcing for well-instrumented reference sites, as previously in SnowMIP

The reference site simulations described in this document can also be performed by models that are not set up for the global simulations in GSWP3 or that lack the atmosphere and ocean couplings necessary for CMIP6 simulations.

2. Forcing data

Model forcing data can be downloaded from http://www.geos.ed.ac.uk/~ressery/ESM-SnowMIP.html. All of the meteorological variables listed in Table 1 are supplied in single files with netCDF and text formats for each site. Tier 1 simulations that all participants should perform use data from in situ measurements, and GSWP3 forcing data with bias corrections to in situ measurements are available for optional Tier 2 experiments. The forcing data for all sites have 1-hour timesteps, starting from snow-free conditions in autumn and covering several complete years to allow model spin up.

Table 1: Short names in ALMA and CMOR conventions, descriptions and units for meteorological forcing variables.

Short name		Description	Units
ALMA	CMOR		
LWdown	rlds	surface downward longwave radiation	W m^{-2}
Psurf	ps	surface pressure	Pa
Qair	hus	near-surface specific humidity	kg kg^{-1}
Rainf	prr	rainfall rate	kg m^{-2} s^{-1}
Snowf	prsn	snowfall rate	kg m^{-2} s^{-1}
SWdown	rsds	surface downward shortwave radiation	W m^{-2}
Tair	ta	near-surface air temperature	K
Wind	ws	near-surface wind speed	m s^{-1}

The convention for forcing file naming is

`met_`*`forcing`*`_`*`site`*`_`*`start`*`_`*`end`*`.`*`format`*

where

forcing	=	`insitu` or `gswp3c` for in situ or bias-corrected GSWP3 data
site	=	site short name, defined in Section 5
start	=	start year
end	=	end year
format	=	`nc` or `txt` for netCDF or plain text files

e.g. the netCDF file containing in situ forcing data for 1 October 1994 to 30 September 2014 at Col de Porte is called `met_insitu_cdp_1994_2014.nc`. The time variable in the netCDF forcing files is in units of hours since 1900-01-01 00:00:00 and variables are labelled with both the ALMA and CMOR names given in Table 1. Plain text forcing files additionally contain relative humidity `RH`. Each line of a plain text forcing file has the format

```
year month day hour SWdown LWdown Rainf Snowf Tair Qair RH Wind Psurf
```

e.g. the first line of the in situ forcing data plain text file for Col de Porte is

```
1994 10 1 1 0.0 337.8 0.0e+00 0.0e+00 284.1 8.458e-03 89.2 0.9 86382
```

3. Model output data

Model outputs are preferred in netCDF format with variable names based on those used in CMIP6 and GSWP3. The netCDF files will have a time dimension for all variables and a level dimension for soil state variables. Flux variables listed in Tables 2 and 3 should be averaged over each forcing data timestep and model grid cell, and state variables in Table 4 should be given at the end of each timestep. Model options for subgrid variability, such as tiling, should be disabled for reference site simulations.

Table 2: Variable names, descriptions and positive directions for surface energy balance components in model outputs. All are in units of W m^{-2}.

Name	Description	Direction
hfds	downward heat flux at ground surface	downward
hfdsn	downward heat flux into snowpack	downward
hfls	surface upward latent heat flux	upward
hfmlt	energy of fusion	solid to liquid
hfrs	heat transferred to snowpack by rain	downward
hfsbl	energy of sublimation	solid to vapour
hfss	surface upward sensible heat flux	upward
rlus	surface upwelling longwave radiation	upward
rsus	surface upwelling shortwave radiation	upward

Table 3: Variable names and descriptions for water balance components in model outputs. All are in units of kg m^{-2} s^{-1}.

Name	Description
esn	liquid water evaporation from snowpack
evspsbl	total water vapour flux from the surface to the atmosphere
evspsblsoi	evaporation and sublimation from soil
evspsblveg	evaporation and sublimation from canopy
mrrob	subsurface runoff
mrros	surface runoff
sbl	sublimation of snow
snm	surface snow melt
snmsl	water flowing out of snowpack
tran	transpiration

Table 4: Names, descriptions and units for state variables in model outputs.

Name	Description	Units
albs	surface albedo	–
albsn	snow albedo	–
cw	total canopy water storage	kg m^{-2}
lqsn	mass fraction of liquid water in snowpack	–
lwsnl	liquid water content of snowpack	kg m^{-2}
mrfsofr	mass fractions of frozen water in soil layers	–
mrlqso	mass fractions of unfrozen water in soil layers	–
mrlsl	masses of frozen and unfrozen moisture in soil layers	kg m^{-2}
snc	snow area fraction	–
snd	snowdepth	m
snw	mass of snowpack	kg m^{-2}
snwc	mass of snow intercepted by vegetation	kg m^{-2}
tcs	vegetation canopy temperature	K
tgs	temperature of bare soil	K
ts	surface temperature	K
tsl	temperatures of soil layers	K
tsn	snow internal temperature	K
tsns	snow surface temperature	K

The forcing data files provide precipitation as separate rainfall and snowfall rates. Repartitioning of total precipitation into rain and snow by models is strongly discouraged because this will make mass balance differences between models much harder to interpret. Water balance outputs from models that cannot accept rainfall and snowfall as separate inputs must include the repartitioned rainfall and snowfall rates `Rainf` and `Snowf` in units of kg m^{-2} s^{-1}.

Groups who are not familiar with netCDF may submit results in plain text files. Three files are required for each simulation, with fixed-width columns in the order

```
year,month,day,hour,hfds,hfdsn,hfls,hfmlt,hfrs,hfsbl,hfss,rlus,rsus
```

for energy balance components,

```
year,month,day,hour,esn,evspsbl,evspsblsoi,evspsblveg,mrrob,mrros,
                    sbl,snm,snmsl,tran
```

for water balance components, and

```
year,month,day,hour,albs,albsn,cw,lqsn,lwsnl,mrfsofr(:),mrlqso(:),
                    mrlsl(:),snc,snd,snw,snwc,tcs,tgs,ts,tsl(:),
                    tsn,tsns
```

for state variables, including a separate column for each of the variables defined on soil layers and denoted by `(:)`. Use `-999` for missing variables.

4. Simulations

Simulations with standard model configurations are to be performed for each site with in situ and GSWP3 forcing data. Tier 2 simulations with model modifications to fix the snow albedo and remove the thermal insulation of snow will be described later. The simulation period should be run at least twice for each site to spin up model state variables, starting from saturated soil conditions and no snow. Outputs should only be returned for the final run.

The requested format for netCDF model output file names is

model_expt_forcing_site_start_end.nc

where

model = model name
expt = `REF`, `FA` or `NI` for reference, fixed albedo or no insulation simulations

e.g. the output file for a CLM5 reference simulation with GSWP3 forcing bias corrected for Col de Porte should be called `CLM5_REF_gswp3c_cdp_1980_2010.nc`.

Text output files should have names

model_table_expt_forcing_site_start_end.txt

where

table = `eb`, `wb` or `sv` for energy balance, water balance or state variable tables

Please direct any questions about the simulations to richard.essery@ed.ac.uk.

5. Sites

Table 5 and a csv file (http://www.geos.ed.ac.uk/~ressery/ESM-SnowMIP/sites.csv) give characteristics for each of the reference sites. Use nominal values of leaf area index area and height for the grassy sites; snow simulations should not be sensitive to the chosen values. An average snow-free albedo is provided where measurements are available; use a value of 0.2 if none is given. Forcing data for several additional reference sites will be provided when they are available.

5.1 BERMS Old Aspen, Saskatchewan, Canada

Even-aged stand of aspen with a thick hazelnut understorey, naturally regenerated after fire in 1919. 10 cm layer of organic litter and peat over a sandy clay loam.

Table 5.1: Old Aspen site characteristics

Short name	oas
Location	53.63°N, 106.20°W
Elevation	600 m
Canopy height	21 m
Leaf area index	winter stem area ~1, summer 3.7 – 5.2
Snow-free albedo (above canopy)	0.14
Simulation period	1 October 1997 to 30 September 2010
Temperature/humidity measurement height	37 m
Wind measurement height	38 m
Reference	Bartlett et al. (2007)

5.2 BERMS Old Black Spruce, Saskatchewan, Canada

Predominantly black spruce, with some tamarack, jack pine and balsam poplar, naturally regenerated after fire in 1894. Sparse understorey. Peat soil over sandy loam and sand with a raised water table.

Table 5.2: Old Black Spruce site characteristics

Short name	obs
Location	53.99°N, 105.12°W
Elevation	629 m
Canopy height	11 m
Leaf area index	3.5 – 3.8
Snow-free albedo (above canopy)	0.08
Simulation period	1 October 1997 to 30 September 2010
Temperature/humidity measurement height	25 m
Wind measurement height	26 m
Reference	Bartlett et al. (2007)

5.3 BERMS Old Jack Pine, Saskatchewan, Canada

Jack pine with a sparse understorey, naturally regenerated after fire in 1915. Coarse sandy soil.

Table 5.3: Old Jack Pine site characteristics

Short name	ojp
Location	53.92ºN, 104.69ºW
Elevation	579 m
Canopy height	13 m
Leaf area index	2.5 – 2.6
Snow-free albedo (above canopy)	0.11
Simulation period	1 October 1997 to 30 September 2010
Temperature/humidity measurement height	28 m
Wind measurement height	29 m
Reference	Bartlett et al. (2007)

5.4 Col de Porte, France

Grassy meadow bordered by coniferous forest. Soils are 30% clay, 60% sand and 10% silt.

Table 5.4: Col de Porte site characteristics

Short name	cdp
Location	45.30ºN, 5.77ºE
Elevation	1325 m
Snow-free albedo	0.2
Simulation period	1 October 1994 to 30 September 2014
Temperature/humidity measurement height	1.5 m above the snow surface
Wind measurement height	10 m
Reference	Morin et al. (2012)

5.5 Reynolds Mountain East, Idaho, USA

Sheltered grassy site in an aspen and fir grove. High organic content in surface soils and 50 cm of silty clay (42% clay, 42% silt) overlying clay (50% clay, 40% silt).

Table 5.5: Reynolds Mountain East site characteristics

Short name	rme
Location	43.19ºN, 116.78ºW
Elevation	2060 m
Simulation period	1 October 1988 to 30 September 2008
Temperature/humidity measurement height	3 m
Wind measurement height	3 m
Reference	Reba et al. (2011)

5.6 Sapporo, Japan

Urban short grass site with frequent deposition of atmospheric aerosols. Clay soil. In situ measurements have been complemented by reanalyses between May and October to form a continuous forcing dataset.

Table 5.6: Sapporo site characteristics

Short name	sap
Location	43.08°N, 141.34°E
Elevation	15 m
Simulation period	1 October 2005 to 30 September 2015
Temperature/humidity measurement height	1.5 m
Wind measurement height	1.5 m
Reference	Niwano et al. (2012)

5.7 Senator Beck, Colorado, US

Alpine tundra with thin soils and exposed bedrock.

Table 5.7: Senator Beck site characteristics

Short name	snb
Location	37.91°N, 107.73°W
Elevation	3714 m
Snow-free albedo	0.2
Simulation period	1 October 2005 to 30 September 2015
Temperature/humidity measurement height	3.8 m
Wind measurement height	4.0 m
Reference	Landry et al. (2014)

5.8 Sodankylä, Finland

Small clearing in a pine plantation with sandy loam soil. Wind speed and radiation are measured above the canopy height, so forcing data have been adjusted for sheltering of the clearing.

Table 5.8: Sodankylä site characteristics

Short name	sod
Location	67.37°N, 26.63°E
Elevation	179 m
Simulation period	1 October 2007 to 30 September 2014
Temperature/humidity measurement height	2 m
Wind measurement height	2 m
Reference	Essery et al. (2016)

5.9 Swamp Angel, Colorado, USA

Sheltered meadow surrounded by subalpine forest. Colluvium.

Table 5.9: Swamp Angel site characteristics

Short name	swa
Location	37.91ºN, 107.71ºW
Elevation	3371 m
Snow-free albedo	0.2
Simulation period	1 October 2005 to 30 September 2015
Temperature/humidity measurement height	3.4 m
Wind measurement height	3.8 m
Reference	Landry et al. (2014)

5.10 Weissfluhjoch, Switzerland

Artificially drained moraine containing clay sediments overlain by serpentine rocks of varying sizes up to 20 cm diameter.

Table 5.10: Weissfluhjoch site characteristics

Short name	wfj
Location	46.83ºN, 9.81ºE
Elevation	2540 m
Snow-free albedo	0.1
Simulation period	1 September 1996 to 31 August 2016
Temperature/humidity measurement height	4.5 m
Wind measurement height	5.5 m
Reference	WSL (2017)

5.11 Bias-corrected GSWP3 forcing data

Three-hour forcing data from 1 October 1980 to 30 September 2010 have been extracted from all of the GSWP3 0.5° grid cells containing ESM-SnowMIP reference sites and interpolated to hourly timesteps. Because site and grid elevations can differ greatly, biases have been removed from all of the forcing variables. The reference heights are 2 m for temperature and humidity, and 10 m for wind speed; these should be interpreted as heights above the canopy top for forested sites. Otherwise, all site-specific parameters should be kept the same as used in the in situ forcing data simulations.

6. Evaluation

Table 6 records the availability of measurements of important snow and soil properties for model evaluation at the reference sites. Basic model evaluation metrics and graphs will be generated automatically and shared with participants. Model outputs will be archived for more sophisticated evaluations. All participants providing site or model data will be included as co-authors on papers using ESM-SnowMIP reference site simulations.

Table 6: Evaluation data at reference sites

	cdp	oas	obs	ojp	rme	sap	sbb	sod	swa	wfj
SWE	×	×	×	×	×	×	×	×	×	×
Snow depth	×	×	×	×	×	×	×	×	×	×

Albedo	×	×	×	×		×	×		×	×
Surface temperature	×	×	×	×		×	×		×	×
Soil temperature	×	×	×	×	×		×	×	×	
Soil moisture	×	×	×	×	×		×	×	×	

7. Submission of results

An ftp address and password for submission of results are available on request from richard.essery@ed.ac.uk. Please submit simulations by the end of November 2018.

8. References

Bartlett, P. A., M. D. MacKay and D. Verseghy (2007). Modified snow algorithms in the Canadian Land Surface Scheme: model runs and sensitivity analysis at three boreal forest stands. *Atmosphere-Ocean*, **43**, 207–222.

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Document history

24 October 2016	Draft for review by participants
26 April 2017	Revised after review
31 August 2018	Instructions for GSWP3 simulations added