Flexible Snow Model user guide

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1 FSM2

The Flexible Snow Model (FSM2) is a multi-physics energy balance model of snow accumulation and melt, extending the Factorial Snow Model (FSM) with additional physics, driving and output options. FSM2 adds forest canopy model options and the possibility of running simulations for more than one point at the same time. For greater efficiency in long simulations than FSM, which selects physics options when it is run, FSM2 options are selected when the model is compiled. Otherwise, FSM2 is built and run in the same way as FSM.

2 Compiling the model

FSM2 is coded in Fortran and consists of subroutines and modules contained in the `src` directory. A linux executable `FSM2` or a Windows executable `FSM2.exe` is produced by running script `compil.sh` or batch file `compil.bat`. Both use the gfortran compiler but could be edited for other compilers. Driving data, physics and output configurations are selected in the compilation script by defining option numbers that are copied to a preprocessor file `src/OPTS.h` before compilation.

2.1 Driving data compilation options

Option number	Description	Options
`DRIV1D`	1D driving data format	0 - FSM format 1 - extended data format with SW components 2 - ESM-SnowMIP format
`DOWNSC`	1D driving data downscaling	0 - no 1 - yes
`DEMHDR`	Header information in DEM for downscaling	0 - none 1 - ESRI format
`SWPART`	Shortwave radiation partition	0 - Total SW radiation used 1 - Diffuse and direct SW calculated 2 - Diffuse and direct SW in extended data
`ZOFFST`	Measurement height offset	0 - Height above ground 1 - Height above canopy top

2.2 Physics compilation options

Option number	Description	Options
`ALBEDO`	Snow albedo	0 - diagnostic temperature function 1 - prognostic age function
`CANMOD`	Forest canopy	0 - zero layer 1 - one layer
`CONDCT`	Thermal conductivity of snow	0 - fixed 1 - function of density
`DENSTY`	Snow density	0 - fixed 1 - function of age

		2 - function of overburden
EXCHNG	Surface-atmosphere exchange	0 - fixed exchange coefficient 1 - function of Richardson number
HYDROL	Snow hydrology	0 - free draining 1 - bucket
SNFRAC	Snow cover fraction	0 - $f_s = h/(h + h_f)$ 1 - $f_s = \tanh(h/h_f)$

2.3 Output compilation options

Option number	Description	Options
TXTOUT	Text output format	0 - sample and average files 1 - ESM-SnowMIP output tables

3 Running the model

FSM2 requires meteorological driving data and namelists to set options and parameters. The model is run with the commands `./FSM2 < nlst.txt` or `FSM2.exe < nlst.txt`, where `nlst.txt` is a text file containing eight namelists described in tables below. All of the namelists have to be present in the order of the tables, but any or all of the variables listed in a namelist can be omitted; defaults are then used.

3.1 Grid dimensions namelist `&gridpnts`

FSM2 can be run at a point, at a sequence of points, with a range of surface characteristics or on a rectangular grid by selecting values for dimensions `Nx` and `Ny`.

Variable	Default	Description
Nsmax	3	Maximum number of snow layers
Nsoil	4	Number of soil layers
Nx	1	Number of grid points in x direction or in sequence
Ny	1	Number of grid points in y direction
ztop_file	none	DEM file name

A DEM file has to be specified if FSM2 is complied with `DOWNSC=1`. Files in the ESRI ASCII raster format (`DEMHDR=1`) have six header lines with grid information, e.g.

```
ncols         1000
nrows         1000
xllcorner     215000
yllcorner     770000
cellsize      5
NODATA_value  -9999
```

If provided, `ncols` and `nrows` overwrite `Nx` and `Ny` from `&gridpnts`.

3.2 Model levels namelist `&gridlevs`

Snow and soil layers are numbered and listed from the top downwards. If layer thicknesses are specified in `&gridlevs`, they must match the numbers of layers specified in `&gridpnts`.

Variable	Default	Description
Dzsnow	0.1, 0.2, snowdepth - 0.3 m	Snow layer thicknesses
Dzsoil	0.1, 0.2, 0.4, 0.8 m	Soil layer thicknesses

3.3 Driving data namelist `&drive` and driving data files

Variable	Default	Description	Used by
met_file	'met'	Driving data file name	
dt	3600 s	Timestep	
zT	2 m	Temperature and humidity measurement height	
zU	10 m	Wind speed measurement height	
lat	0°	Latitude	SWPART=1
noon	12.00	Time of solar noon	SWPART=1
Pscl	0.35 km^{-1}	Precipitation adjustment scale	DOWNSC=1
Tlps	6.5 K km^{-1}	Temperature lapse rate	DOWNSC=1
Tsnw	2°C	Snow threshold temperature	DOWNSC=1
zaws	0 m	Weather station elevation for downscaling	DOWNSC=1

Measurement heights are specified above the ground if FSM2 is compiled with `ZOFFST=0` and above the canopy top if `ZOFFST=1` (required for driving with reanalyses). For simulations at a point or for a set of nearby points with common meteorology, 1D driving data are read from the named text file. Driving variables are arranged in columns of the file and rows correspond with timesteps.

Variable	Units	Description	Used by
year	years	Year	
month	months	Month of the year	
day	days	Day of the month	
hour	years	Hour of the day	
LW	W m^{-2}	Incoming longwave radiation	
Ps	Pa	Surface air pressure	
Rf	kg m^{-2} s^{-1}	Rainfall rate	
RH	%	Relative humidity	
Sf	kg m^{-2} s^{-1}	Snowfall rate	
Ta	K	Air temperature	
Ua	m s^{-1}	Wind speed	
SW	W m^{-2}	Incoming shortwave radiation	DRIV1D=0,2
Sdif	W m^{-2}	Diffuse shortwave radiation	DRIV1D=1
Sdir	W m^{-2}	Direct-beam shortwave radiation	DRIV1D=1
Qa	kg kg^{-1}	Specific humidity	DRIV1D=2

The columns in a 1D driving data file are:

```
year month day hour SW   LW   Sf Rf Ta RH Ua Ps      for DRIV1D=0
year month day hour Sdif Sdir LW Sf Rf Ta RH Ua Ps   for DRIV1D=1
year month day hour SW   LW   Rf Sf Ta Qa RH Ua Ps   for DRIV1D=2
```

3.4 Parameters namelist &params

The parameters used depend on which options are selected and whether a forest canopy is specified.

Parameter	Default	Description	Used by
		Snow albedo parameters	
asmx	0.8	Maximum albedo for fresh snow	
asmn	0.5	Minimum albedo for melting snow	
hfsn	0.1 m	Snow cover fraction depth scale	
Talb	-2°C	Snow albedo decay temperature threshold	ALBEDO=0
Salb	10 kg m^{-2}	Snowfall to refresh albedo	ALBEDO=1
tcld	1000 h	Cold snow albedo decay time scale	ALBEDO=1
tcld	100 h	Melting snow albedo decay time scale	ALBEDO=1
		Snow thermal conductivity parameters	
kfix	0.24 W m^{-1} K^{-1}	Fixed thermal conductivity	CONDCT=0
bthr	2	Thermal conductivity exponent	CONDCT=1

Snow density parameters			
`rho0`	300 kg m^{-3}	Fixed snow density	`DENSTY=0`
`rhof`	100 kg m^{-3}	Fresh snow density	`DENSTY=1,2`
`rcld`	300 kg m^{-3}	Maximum density for cold snow	`DENSTY=1`
`rmlt`	500 kg m^{-3}	Maximum density for melting snow	`DENSTY=1`
`trho`	200 h	Snow compaction time scale	`DENSTY=1`
`eta0`	3.7×10^7 Pa s	Reference snow viscosity	`DENSTY=2`
`snda`	2.8×10^{-6} s^{-1}	Thermal metamorphism parameter	`DENSTY=2`
Turbulent exchange parameters			
`z0sn`	0.01 m	Snow surface roughness length	
`bstb`	5	Atmospheric stability parameter	`EXCHNG=1`
Snow hydraulics parameters			
`Wirr`	0.03	Irreducible liquid water content of snow	`HYDROL=1`
Soil parameters			
`gsat`	0.01 m s^{-1}	Surface conductance for saturated soil	
Solver parameters			
`Nitr`	4	Number of iterations in energy balance calculation	

Canopy parameters		
Parameter	Default	Description
`avg0`	0.1	Snow-free vegetation albedo
`avgs`	0.4	Snow-covered vegetation albedo
`cden`	0.004	Dense canopy turbulent transfer coefficient
`cvai`	4.4 kg m^{-2}	Canopy snow capacity per unit VAI
`cveg`	20	Vegetation turbulent transfer coefficient
`Gcn1`	0.5	Leaf angle distribution parameter
`Gcn2`	0	Leaf angle distribution parameter
`gsnf`	0 m s^{-1}	Snow-free vegetation moisture conductance
`kdif`	0.5	Diffuse radiation extinction coefficient
`kveg`	1.0	Canopy cover coefficient
`rchd`	0.67	Displacement height to canopy height ratio
`rchz`	0.1	Roughness length to canopy height ratio
`tcnc`	240 h	Canopy unloading time scale for cold snow
`tcnm`	2.4 h	Canopy unloading time scale for melting snow

3.5 Site characteristics namelist `&maps` and map files

Parameter	Default	Description
`alb0`	0.2	Snow-free ground albedo
`canh`	2500 `VAI`	Canopy heat capacity (J K^{-1} m^{-2})
`fcly`	0.3	Soil clay fraction
`fsnd`	0.6	Soil sand fraction
`fsky`	1	Sky view fraction
`fveg`	`1 - exp(-kveg VAI)`	Canopy cover fraction
`hcan`	0	Canopy height (m)
`trcn`	`exp(-kdif VAI)`	Canopy transmissivity
`VAI`	0	Vegetation area index
`z0sf`	0.1	Snow-free ground roughness length

Site characteristics can either be left as default values, set to a sequence of `Nx`×`Ny` values in the namelist or read from a named map file. e.g. for a simulation with 10 points, the snow-free ground albedo can be reset to a constant value of 0.1 in `&maps` by including

```
alb0 = 10*0.1
```

or set to a sequence (with spaces or commas) by including
`alb0 = 0.2 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.2 0.2`
or read from a file `albedo.txt` containing 10 values by including
`alb0_file = 'albedo.txt'`
Sky view can be set independently of vegetation cover to allow for grid cells shaded by topography or vegetation in neighbouring cells.

3.6 Initial values namelist `&initial` and start files

Variable	Default	Description
`start_file`	`'none'`	Start file name
`fsat`	4*0.5	Initial moisture content of soil layers as fractions of saturation
`Tsoil`	4*285	Initial temperature of soil layers

Soil temperature and moisture content are taken from the namelist and FSM2 is initialized in a snow-free state by default. If a start file is named, it should be a text file containing initial values for each of the state variables in order:

Variable	Units	Description
`albs(Nx,Ny)`	-	Albedo of snow
`Ds(Nsmax,Nx,Ny)`	m	Thickness of snow layers
`Nsnow(Nx,Ny)`	-	Number of snow layers
`Qcan(Nx,Ny)`	kg kg^{-1}	Canopy air space specific humidity
`Sice(Nsmax,Nx,Ny)`	kg m^{-2}	Ice content of snow layers
`Sliq(Nsmax,Nx,Ny)`	kg m^{-2}	Liquid content of snow layers
`Sveg(Nx,Ny)`	W m^{-2}	Snow mass on canopy
`Tcan(Nx,Ny)`	K	Canopy air space temperature
`theta(Nsoil,Nx,Ny)`	-	Volumetric moisture content of soil layers
`Tsnow(Nsmax,Nx,Ny)`	K	Temperature of snow layers
`Tsoil(Nsoil,Nx,Ny)`	K	Temperature of soil layers
`Tsrf(Nx,Ny)`	K	Surface skin temperature
`Tveg(Nx,Ny)`	K	Vegetation temperature

The easiest way to generate a start file is to spin up the model by running it for a whole number of years without a start file and then rename the dump file produced at the end of the run as a start file for a new run.

3.7 Output namelist `&outputs` and text output files

Variable	Default	Description
`Nave`	24	Number of timesteps in averaged outputs
`Nsmp`	12	Timestep of sample outputs, $\leq$ `Nave`
`runid`	none	Run identifier string
`dump_file`	`'dump'`	Dump file name

A run identifier, if specified, is prefixed on all output file names. If the run identifier includes a directory name (e.g. `runid = 'output/'`), the directory has to exist before the model is run. A metadata file `runid+'runifo'` containing copies of all the namelists and compilation options is written at the start of a run, and the state variables are written to a dump file `runid+dump_file` with the same format as the start file at the end of a run. There are two options for plain text outputs

3.7.1 Text output option `TXTOUT=0`

Flux variable are averaged over `Nave` timesteps and written to file `runid+'ave'`, and state variables are written to file `runid+'smp'` at timestep number `Nsmp` during every averaging period. For the default output frequencies, daily averages and samples at noon will be produced if the driving data has a one-hour timestep and starts at 01:00. Full

timeseries are written if `Nave=1` and `Nsmp=1`.
The sample file has 4 + 3×`Nx`×`Ny` columns:

Variable	Units	Description
`year`	years	Year
`month`	months	Month of the year
`day`	days	Day of the month
`hour`	hours	Hour of the day
`snd(Nx*Ny)`	m	Snow depth
`SWE(Nx*Ny)`	kg m^{-2}	Snow water equivalent
`Sveg(Nx*Ny)`	kg m^{-2}	Canopy snow mass

The average file has 3 + 12×`Nx`×`Ny` columns:

Variable	Units	Description
`year`	years	Year
`month`	months	Month of the year
`day`	days	Day of the month
`alb(Nx*Ny)`	-	Flux-weighted albedo
`G(Nx*Ny)`	W m^{-2}	Ground heat flux
`H(Nx*Ny)`	W m^{-2}	Sensible heat flux to the atmosphere
`Hsrf(Nx*Ny)`	W m^{-2}	Sensible heat flux from the surface
`LE(Nx*Ny)`	W m^{-2}	Latent heat flux to the atmosphere
`LEsrf(Nx*Ny)`	W m^{-2}	Latent heat flux from the surface
`Melt(Nx*Ny)`	kg m^{-2}	Cumulated melt
`Rnet(Nx*Ny)`	W m^{-2}	Net radiation
`Roff(Nx*Ny)`	kg m^{-2}	Cumulated runoff
`Rsrf(Nx*Ny)`	W m^{-2}	Net radiation absorbed by the surface
`Tsrf(Nx*Ny)`	°C	Surface temperature
`Tsoil(Nx*Ny)`	°C	20 cm soil temperature

3.7.2 Text output option `TXTOUT=1`

Energy fluxes, water fluxes and state variables are written on the `Nsmp` timesteps to files `runid+'ebal'`, `runid+'wbal'` and `runid+'svar'` with the formats of ESM-SnowMIP output tables. This option is only available for simulations at a single point (`Nx=Ny=1`).