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 - $f_s = \tanh(h/h_f)$

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`
`rgr0`	5×10^{-5} m	Fresh snow grain radius	
		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
`rgrn(Nsmax,Nx,Ny)`	m	Snow grain radii in layers
`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 vegetation
`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

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 + 6×`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}	Snow mass on vegetation
Tsrf(Nx*Ny)	K	Surface temperature
Tsoil(Nx*Ny)	K	Level 2 soil temperature
Tveg(Nx*Ny)	K	Vegetation temperature

The average file has 4 + 11×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
alb(Nx*Ny)	-	Flux-weighted albedo
G(Nx*Ny)	W m^{-2}	Ground heat flux
Gsoil(Nx*Ny)	W m^{-2}	Heat flux into soil
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

For simulations at a single point (Nx=Ny=1) vertical profiles of snow and soil state variables are written to file runid+'prf'. For each timestep in the profile output file, there is a line

```
year month day hour Nsnow Nsoil
```

followed by Nsnow lines

```
zl Ds rgrain Sice Sliq Tsnow
```

and then Nsoil lines

```
zl Dzsoil theta Tsoil,
```

where zl is the height of the middle of a layer above the ground (negative for soil layers).