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 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 Building 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. Physics and driving data configurations are selected in the compilation script by defining option numbers that are copied to a preprocessor file `src/OPTS.h` before compilation.

Driving data compilation options

Option number	Description	Options
`DRIV1D`	1D driving data format	0 - FSM format 1 - 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`	SW radiation partition	0 - Total SW radation used 1 - Difuse and direct SW calculated
`ZOFFST`	Measurement height offset	0 - Height above ground 1 - Height above canopy top

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 - density function
`DENSTY`	Snow density	0 - fixed 1 - Verseghy (1991) 2 - Anderson (1976)
`EXCHNG`	Surface-atmosphere exchange	0 - fixed 1 - Richardson number stability adjusted
`HYDROL`	Snow hydrology	0 - free draining 1 - bucket

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.

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 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`. If the DEM file contains header information (`DEMHDR=1`), it overwrites `Nx` and `Ny` from `&gridpnts`.

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	Units	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

Driving data namelist `&drive` and driving data files

Variable	Default	Description
`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
Required for 1D downscaling option `DOWNSC=1`		
`Pscl`	0.35 km^{-1}	Precipitation adjustment scale
`Tlps`	6.5 K km^{-1}	Temperature lapse rate
`Tsnw`	2°C	Snow threshold temperature
`zaws`	0 m	Weather station elevation for downscaling

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. The default FSM file format has 12 columns containing the variables listed in the table below. Each row of the file corresponds with a timestep. Text driving files supplied for ESM-SnowMIP have an additional column for specific humidity, and the order of the rainfall and snowfall columns is switched.

Variable	Units	Description
`year`	years	Year
`month`	months	Month of the year
`day`	days	Day of the month
`hour`	years	Hour of the day
`SW`	W m^{-2}	Incoming shortwave radiation
`LW`	W m^{-2}	Incoming longwave radiation
`Sf`	kg m^{-2} s^{-1}	Snowfall rate
`Rf`	kg m^{-2} s^{-1}	Rainfall rate
`Ta`	K	Air temperature
`RH`	%	Relative humidity
`Ua`	m s^{-1}	Wind speed
`Ps`	Pa	Surface air pressure

Parameters namelist `&params`

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

Parameter	Default	Description
All options		
asmx	0.8	Maximum albedo for fresh snow
asmn	0.5	Minimum albedo for melting snow
gsat	0.01 m s^{-1}	Surface conductance for saturated soil
hfsn	0.1 m	Snow cover fraction depth scale
Nitr	4	Number of iterations in energy balance calculation
z0zh	10	Ratio of roughness lengths for momentum and heat
z0sn	0.01 m	Snow surface roughness length
Diagnostic snow albedo option ALBEDO=0		
Talb	-2°C	Snow albedo decay temperature threshold
Prognostic snow albedo option ALBEDO=1		
Salb	10 kg m^{-2}	Snowfall to refresh albedo
tcld	1000 h	Cold snow albedo decay time scale
tcld	100 h	Melting snow albedo decay time scale
Fixed snow thermal conductivity option CONDCT=0		
kfix	0.24 W m^{-1} K^{-1}	Fixed thermal conductivity
Variable snow thermal conductivity option CONDCT=1		
bthr	2	Thermal conductivity exponent
Fixed snow density option DENSTY=0		
rho0	300 kg m^{-3}	Fixed snow density
Prognostic snow density option DENSTY=1		
rcld	300 kg m^{-3}	Maximum density for cold snow
rmlt	500 kg m^{-3}	Maximum density for melting snow
rhof	100 kg m^{-3}	Fresh snow density
trho	200 h	Snow compaction time scale
Prognostic snow density option DENSTY=2		
eta0	3.7×10^7 Pa s	Reference snow viscosity
etaa	0.081 K^{-1}	Snow viscosity parameter
etab	0.018 m^3 kg^{-1}	Snow viscosity parameter
rhoc	150 kg m^{-3}	Critical snow density
rhof	100 kg m^{-3}	Fresh snow density
snda	2.8×10^{-6} s^{-1}	Snow densification parameter
sndb	0.042 K^{-1}	Snow densification parameter
sndc	0.046 m^3 kg^{-1}	Snow densification parameter
Atmospheric stability adjustment option EXCHNG=1		
bstb	5	Atmospheric stability parameter
Bucket hydrology option HYDROL=1		
Wirr	0.03	Irreducible liquid water content of snow
Canopy parameters		
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
gsnf	0 m s^{-1}	Snow-free vegetation moisture conductance
kext	0.5	Canopy 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

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(-kext 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.

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.

Output namelist `&outputs` and 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

Flux variable are averaged over `Nave` timesteps and written to file `ave`, and state variables are written to file `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`. At the end of a run, the state variables are written to a dump file with the same format as the start file. 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.
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

A metadata file runifo is produce containing copies of all the namelists and the physics options for the run.