

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
SWPART	SW radiation partition	0 - Total SW radation used 1 - Difuse and direct SW calculated

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 - Versegghy (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

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 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

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 ¶ms

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
z0zh	10	Ratio of roughness lengths for momentum and heat
z0sn	0.01 m	Snow surface roughness length
Diagnostic snow albedo option ALBED0=0		
Talb	-2°C	Snow albedo decay temperature threshold
Prognostic snow albedo option ALBED0=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	$0.24 \text{ W m}^{-1} \text{ K}^{-1}$	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	$3.7 \times 10^7 \text{ Pa s}$	Reference snow viscosity
etaa	0.081 K^{-1}	Snow viscosity parameter
etab	$0.018 \text{ m}^3 \text{ kg}^{-1}$	Snow viscosity parameter
rhoc	150 kg m^{-3}	Critical snow density
rhof	100 kg m^{-3}	Fresh snow density
snda	$2.8 \times 10^{-6} \text{ s}^{-1}$	Snow densification parameter
sndb	0.042 K^{-1}	Snow densification parameter
sndc	$0.046 \text{ m}^3 \text{ kg}^{-1}$	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
cdcn	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
kext	0.5	Canopy radiation extinction 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 ($\text{J K}^{-1} \text{m}^{-2}$)
fcly	0.3	Soil clay fraction
fsnd	0.6	Soil sand fraction
fsky	$\exp(-k_{\text{ext}} \text{VAI})$	Sky view fraction
fveg	$1 - \exp(-\text{VAI})$	Canopy cover fraction
hcan	0	Canopy height (m)
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 $N_x \times N_y$ 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(N_x, N_y)	-	Albedo of snow
Ds($N_{\text{snow}}, N_x, N_y$)	m	Thickness of snow layers
Nsnow(N_x, N_y)	-	Number of snow layers
Qcan(N_x, N_y)	kg kg^{-1}	Canopy air space specific humidity
Sice($N_{\text{snow}}, N_x, N_y$)	kg m^{-2}	Ice content of snow layers
Sliq($N_{\text{snow}}, N_x, N_y$)	kg m^{-2}	Liquid content of snow layers
Sveg(N_x, N_y)	W m^{-2}	Snow mass on canopy
Tcan(N_x, N_y)	K	Canopy air space temperature
theta($N_{\text{soil}}, N_x, N_y$)	-	Volumetric moisture content of soil layers
Tsnow($N_{\text{snow}}, N_x, N_y$)	K	Temperature of snow layers
Tsoil($N_{\text{soil}}, N_x, N_y$)	K	Temperature of soil layers
Tsrf(N_x, N_y)	K	Surface skin temperature
Tveg(N_x, N_y)	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, $j = N_{\text{ave}}$
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 $4 + 3 \times N_x \times N_y$ 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 $3 + 7 \times N_x \times N_y$ 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
Ho(Nx*Ny)	W m ⁻²	Sensible heat flux
LE(Nx*Ny)	W m ⁻²	Latent heat flux
Melt(Nx*Ny)	kg m ⁻²	Cumulated melt
Rnet(Nx*Ny)	W m ⁻²	Net radiation
Roff(Nx*Ny)	kg m ⁻²	Cumulated runoff
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.