Flexible Snow Model user guide

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Draft, 27 May 2018

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
`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

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

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
`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`	`exp(-kext VAI)`	Sky view fraction
`fveg`	`1 - exp(-kveg 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 `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, ¡= 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.