Flexible Snow Model user guide

Version 2.1.1

March 1, 2025

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). 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   Compiling the model

FSM2 is coded in Fortran and consists of subroutines and modules contained in the `src` directory. An executable `FSM2` is produced by running scripts `compil.sh` or `compil_nc.sh`. Both use the gfortran compiler, and the latter also requires installation of the Fortran netCDF module for writing outputs. Input, 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   Input options

Option	Description	Possible values
DRIV1D	1D driving data format	1 - FSM format
		2 - ESM-SnowMIP format
SWPART	Shortwave radiation partition	0 - SW radiation assumed to be diffuse
		1 - SW radiation split into diffuse and direct-beam components
ZOFFST	Measurement height offset	0 - Height above ground
		1 - Height above canopy top

2.2   Physics options

Option	Description	Possible values
ALBEDO	Snow albedo	1 - diagnostic temperature function
		2 - prognostic age function
CANINT	Canopy interception of snow	1 - linear interception
		2 - nonlinear interception
CANMOD	Canopy model	1 - one layer
		2 - two layers
CANRAD	Canopy radiative transfer	1 - Beer's law
		2 - two-stream approximation
CANUNL	Unloading of canopy snow	1 - time/melt-dependent
		2 - temperature/wind-dependent
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 - Monin-Obukhov stability adjustment
HYDROL	Snow hydrology	0 - free draining
		1 - bucket model
		2 - gravitational drainage
SGRAIN	Snow grain growth	1 - temperature metamorphism
		2 - temperature gradient metamorphism
SNFRAC	Snow cover fraction	1 - linear function of snow depth
		2 - hyperbolic tangent function of snow depth
		3 - asymptotic function of snow depth

2.3 Output options

Option	Description	Possible values
PROFNC	Output format	0 - text output files
		1 - netCDF profile outputs

3 Running the model

FSM2 requires meteorological driving data and namelists to set options and parameters. The model is run with the command ./FSM2 < nlst.txt, where nlst.txt is a text file containing six 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 in a namelist can be omitted; defaults are then used.

3.1 Parameters namelist &params

FSM2 parameter values can be read from namelist &params when the model is run. The parameters used depend on which options are selected and whether a forest canopy is specified by the vegetation characteristics.

Snow parameters	Default	Description	Used by
asmn	0.5	Minimum albedo for melting snow	
asmx	0.85	Maximum albedo for fresh snow	
eta0	3.7×10^7 Pa s	Reference snow viscosity	DENSTY 2
hfsn	0.1 m	Snow cover fraction depth scale	
kfix	0.24 W m^{-1} K^{-1}	Fixed thermal conductivity	CONDCT 0
nhyd	10	Number of snow hydrology substeps	HYDROL 2
rcld	300 kg m^{-3}	Maximum density for cold snow	DENSTY 1
rfix	300 kg m^{-3}	Fixed snow density	DENSTY 0
rgr0	5×10^{-5} m	Fresh snow grain radius	
rhof	100 kg m^{-3}	Fresh snow density	DENSTY 1
rhow	300 kg m^{-3}	Wind-packed snow density	DENSTY 1,2
rmlt	500 kg m^{-3}	Maximum density for melting snow	DENSTY 1
Salb	10 kg m^{-2}	Snowfall to refresh albedo	ALBEDO 2
snda	2.8×10^{-6} s^{-1}	Thermal metamorphism parameter	DENSTY 2
Talb	-2°C	Snow albedo decay temperature threshold	ALBEDO 1
tcld	1000 h	Cold snow albedo decay time scale	ALBEDO 2
tmlt	100 h	Melting snow albedo decay time scale	ALBEDO 2
trho	200 h	Snow compaction time scale	DENSTY 1
Wirr	0.03	Irreducible liquid water content of snow	HYDROL 1,2
z0sn	0.001 m	Snow surface roughness length	

Veg. parameters	Default	Description	Used by
acn0	0.1	Snow-free dense canopy albedo	CANRAD 1
acns	0.3	Snow-covered dense canopy albedo	CANRAD 1
avg0	0.27	Canopy element reflectivity	CANRAD 2
avgs	0.65	Canopy snow reflectivity	CANRAD 2
cvai	3.6×10^4 J K^{-1} m^{-2}	Vegetation heat capacity per unit VAI	
eunl	240 h	exponential unloading timescale	CANUNL 1
gsnf	0.01 m s^{-1}	Snow-free vegetation moisture conductance	
hbas	2 m	Canopy base height	
kext	0.5	Canopy light extinction coefficient	
leaf	20 s$^{1/2}$ m$^{-1/2}$	Leaf boundary resistance	
munl	0.4	Melt unloading fraction	CANUNL 1
svai	4.4 kg m^{-2}	Intercepted snow capacity per unit VAI	
Tunl	1.87×10^5 K s	Temperature unloading parameter	CANUNL 2
Uunl	1.56×10^5 m	Wind unloading parameter	CANUNL 2
wcan	2.5	Canopy wind decay coefficient	

Soil parameters	Default	Description
fcly	0.3	Soil clay fraction
fsnd	0.6	Soil sand fraction
gsat	0.01 m s^{-1}	Surface conductance for saturated soil
z0sf	0.1 m	Snow-free surface roughness length

3.2 Grid dimensions namelist `&gridpnts`

FSM2 can be run at a point or a sequence of `Npnts` points with a range of surface characteristics. The numbers of snow and soil layers can be set, but the number of canopy layers (`Ncnpy`) is determined by compiler option `CANMOD`.

Variable	Default	Description
Npnts	1	Number of points
Nsmax	3	Maximum number of snow layers
Nsoil	4	Number of soil layers

3.3 Grid levels namelist `&gridlevs`

Snow and soil layers are numbered from 1 at the top. If the thicknesses of the layers are changed, they have to match the numbers `Nsmax` and `Nsoil`. The first snow layer and the first soil layer should have the same thickness.

Variable	Default	Description
Dzsnow	0.1, 0.2, 0.4 m	Snow layer thicknesses when not the lowest layer
Dzsoil	0.1, 0.2, 0.4, 0.8 m	Soil layer thicknesses
fvg1	0.5	Fraction of vegetation in upper layer (CANMOD 2)
zsub	1.5 m	Subcanopy wind speed diagnostic height

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

Variable	Default	Description
met_file	'met'	Meteorological 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`)

Measurement heights are specified above the ground if FSM2 is compiled with `ZOFFST 0` and above the canopy top with `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
`year`	years	Year
`month`	months	Month of the year
`day`	days	Day of the month
`hour`	hours	Hour of the day
`LW`	W m^{-2}	Incoming longwave radiation
`Ps`	Pa	Surface air pressure
`Qa`	kg kg^{-1}	Specific humidity
`Rf`	kg m^{-2} s^{-1}	Rainfall rate
`RH`	%	Relative humidity
`Sf`	kg m^{-2} s^{-1}	Snowfall rate
`SW`	W m^{-2}	Incoming shortwave radiation
`Ta`	K	Air temperature
`Ua`	m s^{-1}	Wind speed

The columns in a 1D driving data file are:
```
year month day hour SW 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
```

3.5   Vegetation characteristics namelist &veg and vegetation files

Parameter	Default	Description
`alb0`	0.2	Snow-free ground albedo
`vegh`	0	Canopy height (m)
`VAI`	0	Vegetation area index

Vegetation characteristics can either be left as default values, set to a sequence of `Npnts` values in the namelist or read from a named file. In a simulation with 10 points, for example, the snow-free ground albedo can be reset to a constant value of 0.1 in `&veg` 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'`

3.6   Initial values namelist &initial and start files

Variable	Default	Description
`start_file`	none	Start file name
`fsat`	Nsoil*0.5	Initial soil moisture profile as fractions of saturation
`Tprf`	Nsoil*285	Initial soil temperature profile

Soil temperature and moisture content are taken from the namelist and FSM2 is initialized in a snow-free state by default if there is no start file. If a start file is named, it should be a text file containing initial values for each of the state variables in order:

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Variable	Units	Description
Nsnow(Npnts)	-	Number of snow layers
albs(Npnts)	-	Albedo of snow
Dsnw(Nsmax,Npnts)	m	Thickness of snow layers
Qcan(Ncnpy,Npnts)	kg kg^{-1}	Canopy air space specific humidities
Rgrn(Nsmax,Npnts)	m	Snow grain radii in layers
Sice(Nsmax,Npnts)	kg m^{-2}	Ice content of snow layers
Sliq(Nsmax,Npnts)	kg m^{-2}	Liquid content of snow layers
Sveg(Ncnpy,Npnts)	W m^{-2}	Snow mass on canopy layers
Tcan(Ncnpy,Npnts)	K	Canopy air space temperatures
Tsnow(Nsmax,Npnts)	K	Snow layer temperatures
Tsoil(Nsoil,Npnts)	K	Soil layer temperatures
Tsrf(Npnts)	K	Ground or snow surface temperature
Tveg(Ncnpy,Npnts)	K	Canopy layer temperatures
Vsmc(Nsoil,Npnts)	-	Volumetric moisture content of soil layers

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 renaming 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
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. State variables are written at the end of a run to a dump file runid+dump_file with the same format as the start file. A state file runid+stat and a flux file runid+flux are written to every timestep, and a subcanopy diagnostics file runid+subc is written to if there are any points with VAI > 0.

The state file has $4 + \text{Npnts} \times (4 + \text{Ncnpy} + \text{Nsoil})$ 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(Npnts)	m	Snow depth
SWE(Npnts)	kg m^{-2}	Snow water equivalent
Sveg(Npnts)	kg m^{-2}	Snow mass on vegetation
Tsoil(Npnts*Nsoil)	K	Soil layer temperatures
Tsrf(Npnts)	K	Surface temperature
Tveg(Npnts*Ncnpy)	K	Vegetation layer temperatures

The flux file has $4 + 7 \times \text{Npnts}$ 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
H(Npnts)	W m^{-2}	Sensible heat flux to the atmosphere
LE(Npnts)	W m^{-2}	Latent heat flux to the atmosphere
LWout(Npnts)	W m^{-2}	Outgoing LW radiation

Melt(Npnts)	kg m^{-2} s^{-1}	Surface melt
Roff(Npnts)	kg m^{-2} s^{-1}	Runoff at base of snow
Subl(Npnts)	kg m^{-2} s^{-1}	Sublimation rate
SWout(Npnts)	W m^{-2}	Outgoing SW radiation

The subcanopy file has $4 + 4\times$`Npnts` 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
LWsub(Npnts)	W m^{-2}	Subcanopy downward LW radiation
SWsub(Npnts)	W m^{-2}	Subcanopy downward SW radiation
Tsub(Npnts)	K	Subcanopy air temperature
Usub(Npnts)	m s^{-1}	Subcanopy wind speed

3.8   NetCDF output

Outputs are written to netCDF file `runid+FSM2out.nc` if the model is compiled with `PROFNC 1` (currently only available for point runs).

Variable	Units	Dimensions	Description
Dzsoil	m	Nsoil	Soil layer thicknesses
hfls	W m^{-2}	Ntime	Surface upward latent heat flux
hfss	W m^{-2}	Ntime	Surface upward sensible heat flux
rlus	W m^{-2}	Ntime	Surface upwelling longwave radiation
rsus	W m^{-2}	Ntime	Surface upwelling shortwave radiation
snd	m	Ntime	Snow depth
snm	kg m^{-2} s^{-1}	Ntime	Surface snow melt
snmsl	kg m^{-2} s^{-1}	Ntime	Water flowing out of snowpack
snw	kg m^{-2}	Ntime	Surface snow mass
time	hours	Ntime	Hours since start of run
tsl	K	Ntime	Surface temperature
Dsnw	m	Ntime, Nsmax	Thicknesses of snow layers
lqsn	-	Ntime, Nsmax	Mass fraction of liquid water in snow layers
rgrn	m	Ntime, Nsmax	Grain radii in snow layers
snowrho	kg m^{-3}	Ntime, Nsmax	Densities of snow layers
tsl	K	Ntime, Nsoil	Temperatures of soil layers
tsnl	K	Ntime, Nsmax	Temperatures of snow layers
wflx	kg m^{-2} s^{-1}	Ntime, Nsmax	Water flux into snow layers

4   Example

The commands
`compil.sh`
`./FSM2 < nlst_Alptal.txt`
will compile and run FSM2 using the input file `met_Alptal_0405.txt` for an open site and a forest site at Alptal, Switzerland in 2004 - 2005.