Instructions for SnowMIP2

Modified 14/11/06

INTRODUCTION

SnowMIP2 is a model intercomparison for off-line simulations of snow and surface energy balance in forested environments. Simulations are to be performed for a forested plot and an open plot at five sites: the Boreal Ecosystem Research and Monitoring Sites (BERMS) in Canada, Alptal in Switzerland, Fraser Experimental Forest in the USA, Hitsujigaoka Experimental Forest in Japan and Hyytiälä in Finland. Meteorological data at 30 minute timesteps for complete winters and metadata for each site are supplied; measured precipitation has been gauge-corrected where necessary and partitioned into rain and snow using separate algorithms, supplied by the data providers, for each site (see Appendix A for details). Simulation results will be compared with observations of snow water equivalent, snow depth, snow and soil temperatures, and radiative and turbulent energy fluxes.

SITE DESCRIPTIONS

Forest canopies are characterized by the effective plant area index, L_e, given in the tables below. Appendix B discusses how this parameter was measured for each site and how it should be interpreted.

Alptal

Alptal simulations are to be performed at forested and open sites for 1 October 2002 to 31 May 2003 (11664 timesteps) and 1 October 2003 to 23 May 2004 (11328 timesteps), inclusive.

Forest site

Location	47°3'N, 8°43'E
Elevation	1185 m (880 mb)
Topography	3° slope, west-exposed
Soil	0-10 cm layer: 45% clay, 45% silt 10-45 cm layer: 43% clay, 42% silt
Vegetation	25 m spruce and fir, L_e 2.5, 96% canopy coverage
Snow-free albedo	0.11
Instrument height	35 m

Open site

Location	47°3'N, 8°43'E (200 m from forest site)
Elevation	1220 m (880 mb)
Topography	11° slope, west-exposed
Soil	0-10 cm layer: 45% clay, 45% silt 10-45 cm layer: 43% clay, 42% silt
Vegetation	Short grass
Snow-free albedo	0.19
Instrument height	3.5 m

BERMS

BERMS simulations are to be performed at forested and open sites for 1 September to 30 April, inclusive, for 2002 – 2003 (11616 timesteps) and 2003 – 2004 (11664 timesteps).

Forest site (Old Jack Pine)

Location	53°55'N, 104°42'W
Elevation	579 m (950 mb)
Topography	Level
Soil	Sandy soil (94% sand, 3% clay), organic layer 0-10 cm deep.
Vegetation	12-15 m jack pine, L_e 1.66, 72% canopy closure
Snow-free albedo	0.11
Instrument height	28 m

Open site (2002 clear cut)

Location	53°57'N, 104°39'W (4 km from forest site)
Elevation	579 m (950 mb)
Topography	Level
Soil	Sandy soil (94% sand, 3% clay), organic layer largely absent
Vegetation	Herbaceous colonizers and severely disturbed bare soil
Snow-free albedo	0.16
Instrument height	2 m temperature and humidity, 5 m windspeed

Missing meteorological data from the open site prior to 1 January 2003 have been filled in using data from a nearby 1994 clearcut site. Precipitation data measured in a clearing at the forest site are used for both sites throughout (see Appendix A).

Fraser

Fraser simulations are to be performed at forested and open sites for 1 November 2003 to 31 May 2004 (10176 timesteps) and 1 October 2004 to 31 May 2005 (11664 timesteps), inclusive.

Forest site

Location	39°53'N, 105°53'W
Elevation	2820 m (717 mb)
Topography	17° slope, 305° aspect
Soil	Sandy loam in top metre, clay loam beneath. 10 – 20% coarse material
Vegetation	~ 27 m pine, spruce and fir, L_e 3
Snow-free albedo	0.05
Instrument height	30 m

Open site (1985 clearcut)

Location	39°53'N, 105°53'W (45 m from edge of forest site)
Elevation	2820 m (717 mb)
Topography	17° slope, 305° aspect
Soil	Sandy loam in top metre, clay loam beneath. 10 – 20% coarse material
Vegetation	Sparse trees*, 2 – 4 m tall, L_e 0.4
Snow-free albedo	0.1
Instrument height	4 m

* Meteorological and snow measurements were made in canopy gaps

Hitsujigaoka

Hitsujigaoka simulations are to be performed at forested and open sites for 1 December 1997 to 30 April 1998 inclusive (7248 timesteps).

Forest site

Location	42º59'N, 141º23'E
Elevation	182 m (990 mb)
Topography	Level
Soil	Loam
Vegetation	7 m todo fir, L_e 3, canopy coverage 90%
Snow-free albedo	0.12
Instrument height	9.2 m

Open site

Location	42º59'N, 141º23'E (500 m from forest site)
Elevation	182 m (990 mb)
Topography	Level
Soil	Loam
Vegetation	Short grass
Snow-free albedo	0.17 (assumed)
Instrument height	1.5 m temperature and humidity, 10 m windspeed

Hyytiälä

Hyytiälä simulations are to be performed at forested and open sites for 1 October to 30 April, inclusive, for 2003 – 2004 (10224 timesteps) and 2004 – 2005 (10176 timesteps). The open site is a clearing with short grass, 1 km from the forest site. The forest meteorology datasets should be used for simulations at both sites.

Forest site

Location	61°51'N, 24°17'E
Elevation	181 m (990 mb)
Topography	Level
Soil	Sandy glacial till
Vegetation	15 m Scots pine, L_e 2.4, canopy coverage 70%
Snow-free albedo	0.15
Instrument height	17 m

INITIALIZATION DATA

All simulations start from times when there was no snow on the ground or the canopy. Although initial soil temperatures and moisture contents are not expected to greatly influence snow simulations, these should be set in the same way for all models. For Alptal, initialize all soil layers to 5°C and saturation. Measured profiles of soil temperature and moisture are available for BERMS, Fraser, Hitsujigaoka and Hyytiälä. Data in the tables below should be interpolated to model levels, with deeper levels set to constant values. The specified soil moisture contents may exceed saturation in some layers; initialize these layers as saturated.

BERMS soil temperature (°C)

	Forest site		Open site	
Depth (cm)	1 Sept. 2002	1 Sept. 2003	1 Sept. 2002 *	1 Sept. 2003
2	14.1	12.9	23.1	21.9
5	14.8	13.4	22.3	20.9
10	15.0	13.5	21.4	19.9
20	14.9	13.3	18.8	17.2
50	14.0	12.8	16.7	15.5
100	12.4	12.2	15.4	15.2

BERMS volumetric soil moisture content (m^3 / m^3)

	Forest site		Open site	
Depth (cm)	1 Sept. 2002	1 Sept. 2003	1 Sept. 2002 *	1 Sept. 2003
0 - 15	0.10	0.04	0.15	0.09
15 - 30	0.08	0.04	0.13	0.08
30 - 60	0.07	0.03	0.13	0.10
60 - 90	0.08	0.02	0.12	0.09
90 - 120	0.07	0.01	0.09	0.08
120 - 150	0.05	0.01	–	–

* Soil data are not available for the open site in 2002; these were constructed by applying 2002 – 2003 differences from the forest site to 2003 data at the open site.

Fraser soil temperature (°C)

	Forest site		Open site	
Depth (cm)	1 Nov. 2003	1 Oct. 2004	1 Nov. 2003	1 Oct. 2004
5	3.2	2.6	1.2	2.7
20	3.7	4.2	2.0	3.9
50	4.3	5.6	3.4	6.0

Fraser soil moisture content (m^3/m^3)

	Forest site		Open site	
Depth (cm)	1 Nov. 2003	1 Oct. 2004	1 Nov. 2003	1 Oct. 2004
5	0.05	0.17	0.05	0.14
20	0.03	0.05	0.10	0.08
50	0.11	0.11	0.06	0.07

Hitsujigaoka soil temperature and moisture *

Depth (cm)	Soil temperature(°C)	Soil moisture content (m^3/m^3)
5	0.7	0.43
10	1.7	0.43
20	–	0.44
30	6.2	0.48
100	9.6	0.61
150	10.6	–

* Soil temperature measurements are for 1 December 1997, and soil moistures are averages of 1 December measurements from 2001 to 2004.

Hyytiälä soil temperature (°C) and moisture content (m^3/m^3)

	Soil temperature (°C)		Soil moisture content (m^3/m^3)	
Depth (cm)	1 Oct. 2003	1 Oct. 2004	1 Oct. 2003	1 Oct. 2004
10	8.0	7.7	0.14	0.31
20	8.5	8.9	0.15	0.41
50	8.5	8.9	0.22	0.47

INPUT DATA

Meteorological data for forcing models are provided at 30-minute timesteps for all sites (derived using linear interpolation from 1-hour data for Alptal, Hitsujigaoka and Fraser). For models that require shorter timesteps, linear interpolation should be used. The forcing datasets are provided in ASCII files, each line of which can be read with the Fortran statement

```
READ(5,*) Year,Day,SWdown,LWdown,Snowf,Rainf,Tair,Wind,RHair
```

where

- YEAR = year
- DAY = fractional Julian day
- SWdown = incoming shortwave radiation (Wm^{-2})
- LWdown = incoming longwave radiation (Wm^{-2})
- Snowf = snowfall rate (kg $m^{-2}s^{-1}$)
- Rainf = rainfall rate (kg $m^{-2}s^{-1}$)
- Tair = air temperature (K)
- Wind = windspeed (ms^{-1})
- RHair = relative humidity with respect to water

The naming convention for forcing datasets is

met_*sss*_*ppp*_*yyyy*.txt

where

sss = site identifier
- `Alp` for Alptal
- `Brm` for BERMS
- `Frs` for Fraser
- `Hit` for Hitsujigaoka
- `Hyy` for Hyytiälä

ppp = plot identifier
- `opn` for open plots
- `for` for forested plots

yyyy = year identifier

e.g. the forcing dataset for the Alptal forest in 2003 - 2004 is `met_Alp_for_0304.txt`.

CALIBRATION DATA

To allow some model calibration, snow water equivalent data are given below for one winter at the Alptal, BERMS, Fraser and Hyytiälä forest sites (no calibration data is provided for Hitsujigaoka, as simulations will only be performed for one winter). If you choose to calibrate your model, please provide detailed information on what parameters were changed, how the calibrated values were selected, what values the parameters were set to after calibration, and what the default values of the parameters would have been. Ideally, you should also submit a set of uncalibrated runs.

Alptal 2002-2003

Date	Julian Day	SWE (kg m^{-2})
5 December 2002	339	7
18 December 2002	352	2
9 January 2003	9	3
15 January 2003	15	5
23 January 2003	23	10
30 January 2003	30	41
6 February 2003	37	160
12 February 2003	43	151
13 February 2003	44	159
20 February 2003	51	144
27 February 2003	58	149
6 March 2003	65	142
12 March 2003	71	131
20 March 2003	79	111
27 March 2003	86	61
9 April 2003	99	21
16 April 2003	106	0

BERMS 2002-2003

Date	Julian Day	SWE (kg m^{-2})
19 November 2002	323	10.1
15 January 2003	15	33.9
12 February 2003	43	45.8
14 March 2003	73	56.5
25 March 2003	84	46.9
30 March 2003	89	51.7
2 April 2003	92	53.2
19 April 2003	109	0

Fraser 2003-2004

Date	Julian Day	SWE (kg m^{-2})
26 December 2003	360	74
30 January 2004	30	92
10 March 2004	70	122
21 March 2004	81	120
13 April 2004	104	85
7 May 2004	128	0

Hyytiälä 2003-2004

Date	Julian Day	SWE (kg m^{-2})
5 January 2004	5	18
2 February 2004	33	56
1 March 2004	61	87
22 March 2004	82	94
29 March 2004	89	93
5 April 2004	96	93
12 April 2004	103	61
19 April 2004	110	22
26 April 2004	117	0

OUTPUT DATA

Several output files are required for each simulation; these files may be in either ASCII or NetCDF format. The output variables requested are based on the ALMA conventions (www.lmd.jussieu.fr/~polcher/ALMA), with some additions for canopy snow processes. Variables to be returned for each timestep are listed in the tables below. The output data should be on the same 30-minute time intervals as the input data. State variables should be given at the end of each timestep, fluxes should be average values over a timestep, and storage change variables (DelCanHeat, DelCanSWE etc) should be accumulated over a timestep.

Energy balance components

Variable	**Definition**	**Units**	**Positive direction**
Hcan	Sensible heat flux from the canopy	W/m^2	Out of canopy
Hsrf	Sensible heat flux from the surface	W/m^2	Upward
H	Total sensible heat flux to the atmosphere	W/m^2	Upward
LEcan	Latent heat flux from the canopy	W/m^2	Out of canopy
LEsrf	Latent heat flux from the surface	W/m^2	Upward
LE	Total latent heat flux to the atmosphere	W/m^2	Upward
LWnetCan	Net longwave radiation absorbed by canopy	W/m^2	Into canopy
LWdnSrf	Longwave radiation incident on the surface	W/m^2	Downward
LWnetSrf	Net longwave radiation absorbed by surface	W/m^2	Downward
LWup	Total outgoing longwave radiation	W/m^2	Upward
SWnetCan	Net shortwave radiation absorbed by canopy	W/m^2	Into canopy
SWdnSrf	Shortwave radiation incident on the surface	W/m^2	Downward
SWnetSrf	Net shortwave radiation absorbed by surface	W/m^2	Downward
SWup	Total outgoing shortwave radiation	W/m^2	Upward
G	Heat flux into the ground	W/m^2	Downward
QfCan	Energy of canopy water phase changes	W/m^2	Solid to liquid
QfSrf	Energy of snowpack phase changes	W/m^2	Solid to liquid
QaCan	Heat advected to the canopy by precipitation	W/m^2	Downward
QaSrf	Heat advected to the surface by precipitation	W/m^2	Downward
DelCanHeat	Timestep change in canopy heat storage	J/m^2	Increase
DelSnowHeat	Timestep change in snowpack heat storage	J/m^2	Increase

Water balance components

Variable	**Definition**	**Units**	**Positive direction**
Evap	Sum of all evaporation sources	kg/m^2/s	Upward
Ecan	Evaporation from canopy liquid water	kg/m^2/s	Out of canopy
Esrf	Evaporation from surface liquid water	kg/m^2/s	Upward
Infil	Infiltration into the soil	kg/m^2/s	Downward
Qs	Surface runoff	kg/m^2/s	Out of gridcell
SnowfSrf	Solid precipitation rate at the surface	kg/m^2/s	Downward
SubCan	Sublimation from canopy snow	kg/m^2/s	Out of canopy
SubSrf	Sublimation from surface snow	kg/m^2/s	Upward
RainfSrf	Liquid precipitation rate at the surface	kg/m^2/s	Downward
SmCan	Net solid to liquid phase change in canopy	kg/m^2/s	Solid to liquid
SmSrf	Net solid to liquid phase change in snowpack	kg/m^2/s	Solid to liquid
Tcan	Canopy transpiration	kg/m^2/s	Upward
DelCanSWE	Change in canopy snow mass	kg/m^2	Increase

DelCanWat	Change in canopy liquid water storage	kg/m^2	Increase
DelSrfSWE	Change in snowpack mass	kg/m^2	Increase
DelSrfWat	Change in surface liquid water storage	kg/m^2	Increase

Note that the surface precipitation rates should include unloading or drip beneath canopies. Esrf is evaporation from ponded surface water and liquid water in snow.

State variables

Variable	**Definition**	**Units**
SrfT	Ground or snowpack surface temperature	K
CanT	Canopy surface temperature	K
SnowTemp	Depth-averaged snow temperature	K
SoilTemp	Surface soil layer temperature	K
CanSWE	Canopy snow mass (liquid and frozen)	kg/m^2
CanWat	Canopy liquid water storage	kg/m^2
SrfSWE	Surface snowpack mass (liquid and frozen)	kg/m^2
SrfWat	Surface liquid water storage	kg/m^2
SoilMoist	Surface soil layer moisture content	kg/m^2
SnowDepth	Snow depth	m
SnowFrac	Fraction of surface with snowcover	-
CanLiqFrac	Mass fraction of liquid water in canopy snow	–
SrfLiqFrac	Mass fraction of liquid water in snowpack	–
SMFrozFrac	Frozen fraction of surface soil layer moisture	–

Note that the canopy and surface snow stores include frozen and liquid water in snow; the canopy and surface liquid water stores are for water not held in snow.

Snow profiles

Models with multi-layer snow schemes should also return profile information

Variable	**Definition**	**Units**
Nsnow	Number of snow layers	–
SnowTempL	Layer temperature	K
SWEL	Layer mass (liquid and frozen)	kg/m^2
SliqFracL	Mass fraction of liquid water in layer	–
SnowDepthL	Depth of layer	m
GrainSizeL	Snow grain size in layer	mm

Energy and water fluxes should satisfy the following conservation equations, which are also illustrated schematically in Appendix C.

Canopy energy balance:

```
SWnetCan + LWnetCan – Hcan – LEcan – QfCan + QaCan
                                    = DelCanHeat  / timestep
```

Surface snowpack energy balance:

```
SWnetSrf + LWnetSrf – Hsrf – LEsrf – QfSrf + QaSrf – G
                                    = DelSnowHeat / timestep
```

Canopy mass balance:

```
Snowf – SnowfSrf – SubCan + Rainf – RainfSrf - Ecan
                              = (DelCanWat + DelCanSWE) / timestep
```

Surface mass balance:

```
SnowfSrf – SubSrf + RainfSrf – Esrf - Infil - Qs
                              = (DelSrfWat + DelSrfSWE) / timestep
```

Rainf and Snowf are the prescribed rainfall and snowfall rates from the driving data. Returned results will be automatically tested for consistency by checking that, averaged over the length of each simulation, these equations balance within 3 Wm^{-2} for energy and 10^{-7} kg $m^{-2}s^{-1}$ for water at each site. We encourage participants to perform these checks themselves before submitting results. Note, also, the flux continuity equations:

```
Evap = Esrf + SubSrf + Ecan + SubCan + Tcan
H = Hcan + Hsrf
LE = LEcan + LEsrf
```

If results are returned in ASCII format, they should be written as follows:

```
C Energy balance components
      WRITE(10,100) Year,Day,
     &              Hcan,Hsrf,H,LEcan,LEsrf,LE,
     &              LWnetcan,LWdnsrf,LWnetsrf,LWup,
     &              SWnetcan,SWdnsrf,SWnetsrf,SWup,
     &              G,Qfcan,Qfsrf,Qacan,Qasrf,
     &              DelCanHeat,DelSnowHeat
100   FORMAT(i4,1x,f7.3,19(1x,f9.3),2(1x,f12.3))
C Water balance components
      WRITE(20,200) Year,Day,
     &              Evap,Ecan,Esrf,Infil,QS,
     &              SnowfSrf,SubCan,SubSrf,
     &              RainfSrf,SmCan,SmSrf,Tcan,
     &              DelCanSnow,DelCanWat,DelSrfSWE,DelSrfWat
200   FORMAT(i4,1x,f7.3,12(1x,e10.3),4(1x,f8.3))
C State variables
      WRITE(30,300) Year,Day,
     &              SrfT,CanT,SnowTemp,SoilTemp,
     &              CanSWE,CanWat,SrfSWE,SrfWat,SoilMoist,
     &              SnowDepth,SnowFrac,CanLiqFrac,
     &              SrfLiqFrac,SMFrozFrac
300   FORMAT(i4,1x,f7.3,9(1x,f8.3),5(1x,f5.3))
C Snow profiles (for multi-layer models)
      WRITE(40,400) Year,Day,Nsnow
      DO N = 1, Nsnow
        WRITE(40,410) N,SnowTempL,SWEL,SliqFracL,
     &                SnowDepthL,GrainSizeL
      ENDDO
400   FORMAT(i4,1x,f7.3,1x,i3)
410   FORMAT(i3,1x,f7.3,1x,f8.3,3(1x,f5.3))
```

Missing data indicators are not necessary in NetCDF, but it is essential that all variables should be included if using ASCII; set variables not calculated by your model to zero or use a missing data indicator of -999. This includes canopy variables that are missing in the simulations for open sites.

The naming convention for output datasets is

mmm_sss_ppp_yyyy_tab.ext

where

mmm = model identifier (to be assigned)

sss, *ppp* and *yyyy* = site, plot and year identifiers as for the forcing datasets

tab = data table identifier

`eb` for energy balance components

`wb` for water balance components

`sv` for state variables
`sp` for snow profiles (optional)
ext = file extension
`txt` for ASCII files
`nc` for NetCDF files

e.g. an ASCII file containing energy balance components simulated by the model MSM for the Alptal forest in 2003 - 2004 would be named `MSM_Alp_for_0304_eb.txt`. Identifiers for each participating model will be posted in the participants list on the SnowMIP2 website (http://users.aber.ac.uk/rie/participants.htm).

SIMULATION PROCEDURES

For surface pressure, use the constant values given in the site description tables for every timestep. Although canopy coverage is quoted in the tables, we suggest that it will be more appropriate to set canopy coverage to 100% for simulations on point scales; canopy gaps are implicitly included in effective plant area indices (PAI) measured by optical methods anyway. For models that represent fractional snowcover on the ground or the canopy, output data should be returned as gridbox averages. All of the open sites, apart from at Fraser, have short vegetation which is submerged by snow; exact values of vegetation parameters for these sites should have little influence on snow simulations, so vegetation height and PAI can be set to small nominal values (e.g. 5-10 cm height, PAI = 1.0). For models that require all forcing data to be on the same level and do not have their own interpolation methods, windspeeds should be interpolated to the temperature and humidity measurement height according to a logarithmic profile

$$U(z_T) = \frac{\log(z_T / z_0)}{\log(z_U / z_0)} U(z_U),$$

where z_T and z_U are temperature and windspeed measurement heights taken from the site description tables and z_0 is the modelled surface roughness length.
Radiation and precipitation data have been projected to unit surface area for the sloping sites (Alptal and Fraser). Energy and mass balance simulations can therefore be carried out as if these sites were level.

DATA EXCHANGE

An ftp address for collection of the forcing datasets and return of the output datasets will be sent to registered participants by email. The data providers retain ownership of the forcing and evaluation datasets, and these are provided for use in SnowMIP2 only; requests to use data for other purposes after the completion of SnowMIP2 can be directed through the SnowMIP2 organizers.

The deadline for return of results is 1 December 2006.

Please send any queries to SnowMIP2@aber.ac.uk, and check the list under http://users.aber.ac.uk/rie/qanda.htm for answers to previous questions.

APPENDIX A: CORRECTION AND PARTITIONING OF PRECIPITATION

Total precipitation was measured by weighing gauges at each site. Gauge-corrected precipitation data were partitioned using site-specific methods suggested by the data providers. For a timestep with total precipitation rate P and fraction F_{snow} falling as snow, the precipitation was divided into rainfall and snowfall rates Rainf = $(1-F_{snow})P$ and Snowf = $F_{snow}P$

Alptal

Precipitation was measured at a sheltered site and no gauge correction was considered to be necessary. Total precipitation is partitioned according to air temperature T_a, with fraction

$$F_{snow} = \begin{cases} 0 & T_a \geq 1.5°C \\ 1 - T_a/1.5 & 0°C < T_a < 1.5°C \\ 1 & T_a \leq 0°C \end{cases}$$

falling as snow.

BERMS

For air temperatures below 2ºC and windspeed U, precipitation rates were corrected by dividing by exp(0.0055-0.133*U*). Above 2°C, precipitation rates were not adjusted for windspeed. The fraction falling as snow is

$$F_{snow} = \begin{cases} 0 & T_a \geq 6°C \\ 1 + 0.04666T_a - 0.15038T_a^2 - 0.01509T_a^3 + 0.0204T_a^4 - 0.00366T_a^5 + 0.0002T_a^6 & \\ 1 & T_a \leq 0°C \end{cases}$$

Fraser

No correction was applied to precipitation amounts; windspeeds are generally low, and the WMO correction for the gauge used gives at most a 3% increase in solid precipitation. Based on observations by the data providers that rain rarely occurs during the period of snowcover, precipitation is classified as snow at air temperatures below 2ºC and rain above.

Hitsujigaoka

Precipitation rates were corrected by multiplying by 1 + *mU*, with *m* = 0.128 for snow and 0.0192 for rain. The fraction falling as snow is

$$F_{snow} = \begin{cases} 1 - 0.5\exp[-2.2(1.1 - T_w)^{1.3}] & T_w < 1.1°C \\ 0.5\exp[-2.2(T_w - 1.1)^{1.3}] & T_w \geq 1.1°C \end{cases}$$

for wet bulb temperature T_w.

Hyytiälä

Daily precipitation amounts were measured with a shielded gauge in a clearing 1 km from the forest site; no correction was applied. Cloud amounts were estimated from temperature and humidity as described by Liston and Elder (2006), and daily precipitation was divided equally between half-hour periods with cloud cover exceeding 70%. Total precipitation is partitioned into snow and rain using a linear function between 0 and 2°C.

APPENDIX B: MEASUREMENT OF LEAF AREA INDICES

Leaf area index (LAI) is used in parametrizations of radiative and turbulent fluxes beneath canopies, interception of precipitation and (less importantly for SnowMIP2) transpiration. Several different definitions of LAI are in common use, and several methods are used for measuring it, including destructive sampling, ground-based optical methods, remote sensing and allometric relationships with other canopy parameters that are easier to measure. It is important to consider how measured values of LAI relate to the parameters required by models. For definiteness, we follow the definitions and notation of Chen et al. (1997).

Optical measurements of LAI are based on inversions of Beer's Law, and variants of Beer's Law are commonly used to parametrize sub-canopy radiation. Viewing a canopy from the ground, the gap fraction at zenith angle θ is

$$P(\theta) = \exp\left[-\frac{G(\theta)}{\cos\theta}\Omega L_t\right]$$

where L_t is a plant area index including leaves and wood, and G is a projection coefficient determined by leaf orientations; for example, G is equal to $\cos\theta$ for horizontal leaves or 0.5 for randomly oriented leaves. Beer's Law is obtained by assuming a random spatial distribution of canopy elements and then introducing the index Ω to account for clumping. The product $L_e = \Omega L_t$ is an effective plant area index; L_e and Ω can both be determined by measurements of gap fraction or transmission at multiple zenith angles. Chen et al. (1997) then define LAI, L, as "half the total leaf per unit ground surface area" and calculate it as

$$L = (1-\alpha)\frac{L_e}{\Omega}$$

where α is the ratio of woody to total area, which is difficult to measure optically for evergreen canopies. As both needles and stems intercept radiation and precipitation, we concentrate on the plant area indices L_t and L_e here.

ALPTAL

Hemispherical photographs analysed using the Hemisfer software (www.wsl.ch/wald/dl/hemisfer/index-en.php) gave $L_e = 2.5$ and $L_t = 4.2$.

BERMS

Leaf area indices have been measured using several methods and at several locations around the BERMS Old Jack Pine site (Eccleston and Regier, 2004). Measurements using the TRAC instrument (Chen and Cihlar, 1995) along the transect used for snow surveys give $L_e = 1.66$ and $L_t = 2.7$. Chen et al. (1997) estimated $\alpha = 0.32$ for this site, from which $L = 1.84$.

Fraser

Kaufmann et al. (1982) developed allometric relationships between total leaf area and trunk diameter by destructive sampling of trees in the Fraser Experimental Forest. These relationships were used with inventory and dbh measurements of trees within five 10 m radius subsamples at the forest site to give $L = 3.68$, assuming horizontal leaf orientation. Assuming $\alpha = 0.25$ and $\Omega = 0.6$ then gives $L_e \approx 3$.

Hitsujigaoka

Destructive sampling of three representative trees was used to estimate $L_t = 6$ (Nakai et al., 1999), and a tentative value of $L_e = 3$ is obtained from this (Takeshi Yamazaki, personal communication).

Hyytiälä

Inventory measurements of trees in 19 sample plots were used with locally determined conversion factors to obtain an all-sided leaf area index of 6 (Vesala et al. 2005), from which $L_t = 3$. Assuming $\alpha = 0.25$ and $\Omega = 0.6$ then gives $L_e = 2.4$.

Land Surface Schemes in many global and regional models require biophysical canopy information at larger scales than can be provided by the ground-based measurements discussed above. Leaf area indices are often classified by land cover or derived from allometric relationship in dynamic vegetation models. Relationships between LAI and spectral vegetation indices (SVI) derived from satellite remote sensing, such as the normalized difference vegetation index (NDVI), may give more realistic spatial and temporal variations in LAI. SVI are principally derived using optical remote sensing and the spectral contrast between leaf absorption and reflectance of incoming radiation in red and near infrared wavelengths. These techniques have been refined using multispectral and hyperspectral data products, seasonal differentiation between canopy and subcanopy characteristics and field validation.

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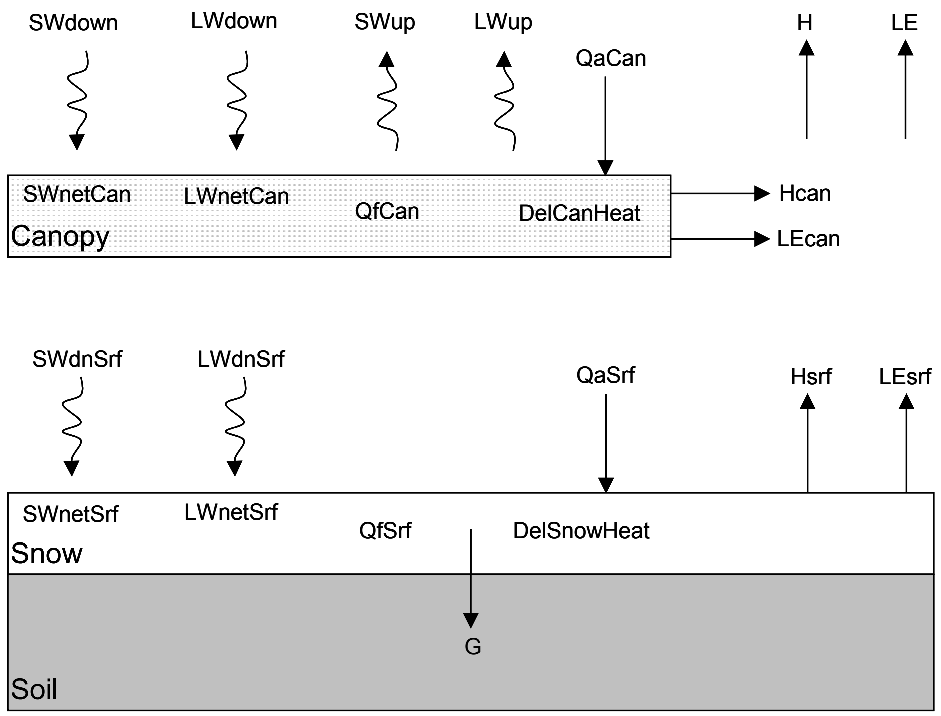
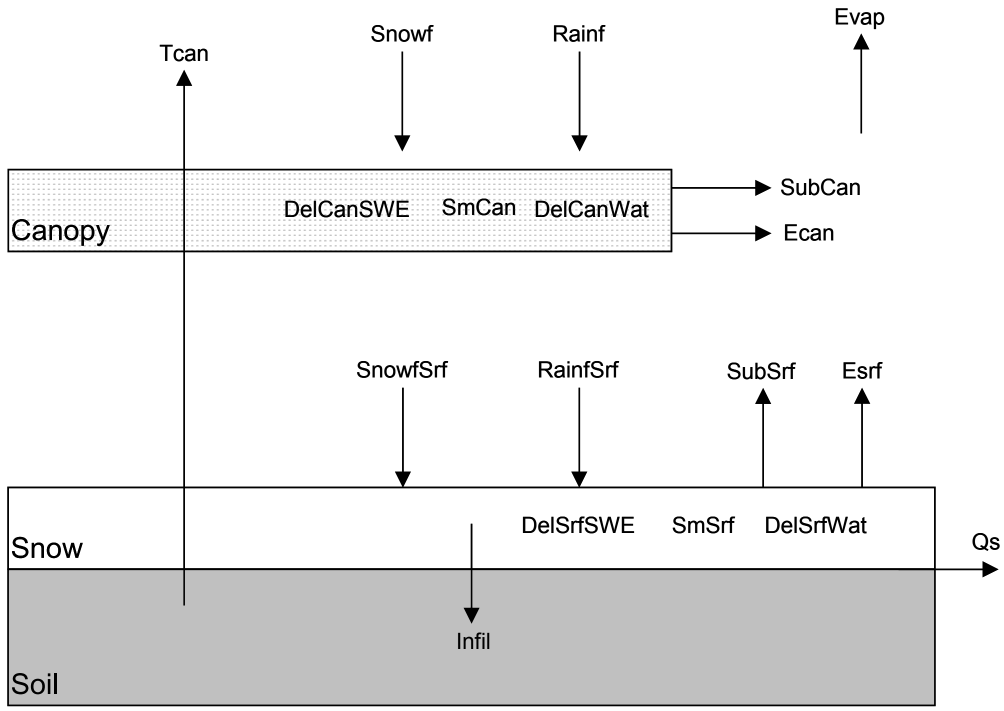
APPENDIX C: ENERGY AND MASS BALANCE SCHEMATICS

Energy balance



Water balance



DOCUMENT HISTORY

21 April 2006
First draft
Sent to data providers

3 May 2006
Additional information on LAI added (pages 1 and 2)
Descriptions of canopy flux sign conventions revised (page 5)
Water balance table, balance equations and format statements revised (pages 6 and 7)
Posted on website and sent to model participants

12 June 2006
Snow-free albedos and canopy coverage added to site descriptions (pages 1 and 2)
SnowFrac added to the output data (page 6)
Guidance on simulation procedures added (page 8)
Appendices on precipitation, LAI and schematic balance equations added (pages 9 to 12)

25 July 2006
Fraser site descriptions, initialization data and calibration data added

14 November 2006
Hitsujigaoka soil moisture data corrected
Hyytiälä site descriptions, initialization data and calibration data added