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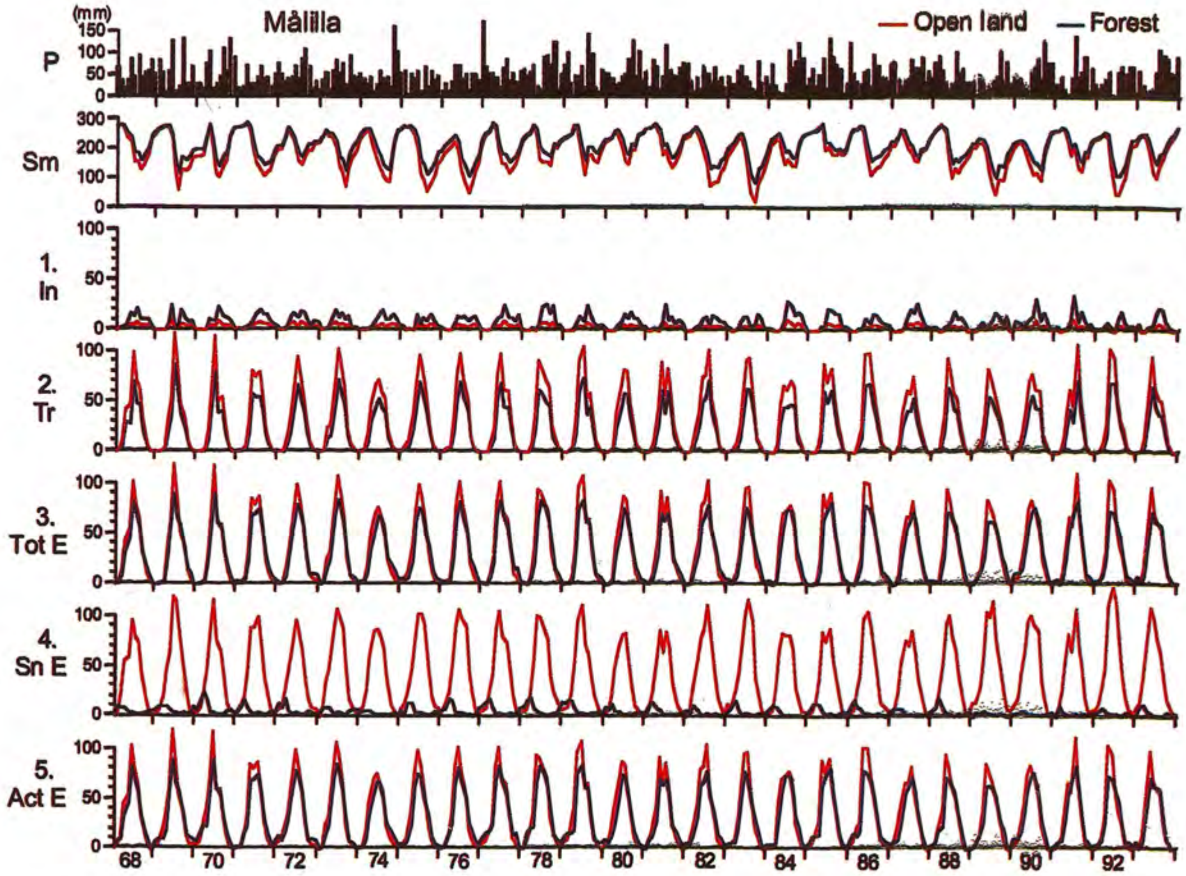

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Abstract/Sammandrag

This work was initiated in order to improve the evapotranspiration data used in the HBV model. Evapotranspiration is calculated consecutively by the Penman-Monteith equation using three-hourly SYNOP observations transformed to values of net radiation, water vapour deficit and data necessary for evaluating aerodynamical resistance and surface resistance. Transpiration, rainfall interception and a simple treatment of winter evaporation are included. Soil moisture is used for calculating the surface resistance and it is updated three-hourly with the soil moisture accounting routine of the HBV model regarding the contributions from rainfall and snow melt. Then soil moisture is reduced due to total evapotranspiration.

Two main parts have been developed and are described here:

1. A program for interpolation of missing SYNOP observations and

2. The evapotranspiration model.

Evapotranspiration is calculated for six SYNOP stations used in the HBV model. Using literature parameter values for open land and forest, the calculated transpiration, interception evaporation and snow evaporation are found to assign reasonable values. Only limited tests against measured evapotranspiration have been made, such as some comparisons with winter data from the NOPEX main site in Norunda north of Uppsala. A comparison is made with evapotranspiration data obtained from calibrations of the HBV model. The performance of the evaporation values in the HBV model remains to be tested.

Key words/sök-, nyckelord
Evapotranspiration, Penman-Monteith equation, surface resistance, aerodynamical resistance, SYNOP data, HBV model, soil moisture.

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1. Introduction

Evapotranspiration E from the earth surface is the sum of two parts:

- Evaporation from ice, snow, water surfaces and bare soil.
- Transpiration from vegetation via dry parts of leaves or needles - has passed through the roots.

These two often occur at the same time. Instead of evaporation, there can be condensation to the earth surface.

Evapotranspiration is a part of the water balance of the earth surface (E in mass units: kg m^{-2} s^{-1}). It is also a part of the energy balance (LE in energy units, W m^{-2}, where L is the latent heat of vaporization):

$$R_n - G = H + LE$$

R_n - net radiation flux	G - energy flux to heat storage in soil and vegetation
H - sensible heat flux	LE - latent heat flux

Evapotranspiration models must be tested and verified against direct measurements. The eddy correlation method is nowadays the most commonly used method to measure evapotranspiration from a meteorological mast. The air humidity and the vertical wind speed component are recorded several times per second at some metres above the surface or vegetation tops. The deviations from their respective time averages (over 20 - 60 minutes) of the fluctuations of these two variables are used to calculate the evapotranspiration flux. The principle is that if, for example, the upward wind fluctuations are more humid than the downward wind fluctuations, then a net upward water vapour flux takes place. The vertical wind speed is often measured by a so-called sonic anemometer and air humidity often by a infrared gas analyzer using infrared light absorption of water vapour.

Grelle (1997) has performed and studied measurements of evaporation from the main forest site (Norunda) in the NOPEX area (Halldin et al. 1998) north of Uppsala in Sweden. Measurements are made continuously of sensible heat flux and latent heat flux by the eddy correlation method at three levels above the forest. In daytime, 80% of the flux events recorded at 35 m have been calculated to come from forest or field areas 80 m to 600 m upwind, while the instruments at the two larger heights (70 m and 100 m) "see" areas 150 m to 3000 m from the mast (Grelle 1997 and Grelle et al. 1997). The source areas are most close to the mast in unstable and convective conditions. In the NOPEX area the eddy correlation method and other micrometeorological methods have been used to record evapotranspiration simultaneously from forests, agricultural fields and lake sites.

The task of this work is to calculate the evapotranspiration continuously, for use as a loss term in the water balance of the HBV model. The traditional estimates of evapotranspiration in the HBV model are based on potential evapotranspiration usually using monthly standard values calculated by the Penman formula (Penman 1948). Gardelin and Lindström (1997) estimated evapotranspiration from the Priestley-Taylor equation using primarily net radiation calculated from observations at some SYNOP stations.

This work was initiated in order to improve the evapotranspiration data used in the HBV model. Evapotranspiration is calculated consecutively by the Penman-Monteith equation using three-hourly SYNOP observations transformed to values of net radiation, water vapour deficit and data necessary for evaluating aerodynamical resistance and surface resistance. Transpiration, rainfall interception and a simple treatment of winter evaporation are included.

Two main parts have been developed here:

1. A program for interpolation of missing SYNOP observations and

2. The evapotranspiration model.

Only limited regard to measured evapotranspiration has been made here, such as some use of winter data from NOPEX site in Norunda. Evapotranspiration calculations are made for six SYNOP stations used in the HBV model (Table 4). A comparison is made with evapotranspiration obtained from calibrations of the HBV model.

2. Interpolation of missing SYNOP observations.

The interpolation code developed for this study, uses SYNOP data prepared for use in an air pollution model (Omstedt 1988). The ouput is data of the same format but with interpolation of missing data when possible.

An interpolation program has been made to interpolate missing SYNOP data at three-hourly observation occasions. Interpolation has been made separately

- within nighttime (18, 21, 00, 03 and 06 UTC) and

- within daytime (06, 09, 12, 15 and 18 UTC).

The interpolation gives data at "0" interpolated from data at "1" for cases (position indicates the corresponding observation time): 11101, 11011, 10111, 11001, 10101, 10011, 10001. Before 1970 the most common configuration was that data exist only at 06, 12 and 18 UTC corresponding to 10001 in nighttime and 10101 in daytime.

Wherever possible, interpolation and completion is made in the code of the following necessary variables in the following order: 1) wind speed, 2) air temperature, 3) dew point temperature, 4) cloudiness, 5) code number for present weather (ww), 6) precipitation and 7) air pressure. The SYNOP observations are described the SMHI manual "Meteorologiska koder".

1). Wind speed is interpolated linearly.

2) and 3). For temperature and dew point temperature, a monthly based, empirical, non-linear interpolation is made. The corrections have been deduced from a set of hourly observations at Uppsala Airport. If a correction is added to an observed value, the expected "average" value for the current month and hour is obtained. The corrections are given in Tables 1 and 2. For temperature the mean corrections are up to minus 4 degrees in summer afternoons and mostly within 0.5 degrees for dew point temperature.

Table 1. Corrections of air temperature (C) based on observations from Uppsala Airport from 1959 to 1984. Horizontally are given data for 00, 03, 06, 09, 12, 15, 18, 21 UTC. Vertically are shown January to December.

0.3,	0.4,	0.3,	0.2,	-0.8,	-0.5,	-0.1,	0.2
0.9,	1.2,	1.3,	0.4,	-1.8,	-1.9,	-0.4,	0.4
1.6,	2.3,	2.4,	-0.2,	-2.7,	-3.0,	-0.9,	0.5
2.6,	3.3,	2.0,	-1.2,	-3.3,	-3.4,	-1.3,	1.2
3.8,	4.8,	1.6,	-2.0,	-3.9,	-4.0,	-1.9,	1.6
4.1,	4.9,	1.0,	-2.0,	-3.7,	-3.8,	-2.0,	1.6
3.5,	4.3,	1.1,	-1.8,	-3.4,	-3.5,	-1.8,	1.4
3.0,	3.9,	1.7,	-1.8,	-3.6,	-3.7,	-1.3,	1.6
2.1,	2.6,	1.9,	-1.2,	-3.2,	-3.1,	-0.4,	1.2
1.1,	1.5,	1.4,	-0.4,	-2.3,	-1.9,	-0.1,	0.7
0.4,	0.5,	0.5,	0.0,	-1.1,	-0.6,	-0.1,	0.3
0.3,	0.4,	0.2,	0.1,	-0.7,	-0.4,	-0.1,	0.1

Table 2. Corrections of dew point temperature (C) based on observations from Uppsala Airport as given in Table 1.

0.27,	0.27,	0.20,	0.06,	-0.49,	-0.26,	-0.09,	0.07
0.46,	0.71,	0.74,	0.10,	-0.82,	-0.76,	-0.44,	0.04
0.22,	0.63,	0.76,	-0.28,	-0.52,	-0.21,	-0.38,	-0.24
-0.15,	0.24,	-0.15,	-0.01,	0.15,	0.24,	0.00,	-0.33
0.05,	0.23,	-0.36,	-0.08,	0.01,	0.10,	0.17,	-0.10
-0.17,	-0.07,	-0.55,	0.03,	0.20,	0.36,	0.31,	-0.10
-0.10,	0.22,	-0.56,	0.04,	0.26,	0.31,	0.13,	-0.29
-0.27,	0.26,	-0.51,	0.19,	0.42,	0.58,	-0.12,	-0.58
0.10,	0.48,	0.15,	-0.36,	-0.09,	0.25,	-0.36,	-0.18
0.19,	0.36,	0.39,	-0.41,	-0.35,	-0.10,	-0.21,	0.11
0.17,	0.29,	0.30,	-0.02,	-0.42,	-0.28,	-0.11,	0.09
0.21,	0.27,	0.19,	0.03,	-0.44,	-0.31,	-0.10,	0.14

Example:

Time UTC	06	12	18
Observed/wanted temp. (C)	10.0	x	10.0
Corrections from Table 1 (June)	1.0	-3.7	-2.0
"Average" temp.	11.0	x-3.7	8.0

Linear interpolation of "average temp.":

x - 3.7 = (11.0 + 8.0) / 2 = 9.5 x = 3.7 + 9.5 = 13.2 C

4). Cloudiness n, has been interpolated linearly disregarding observations with fog (n=9).

5). ww. 06 UTC and 18 UTC are the hours for 12-hourly precipitation amounts. The ww code (if missing) has been put to 63 (rainfall) if temperature exceeds 2 C or 73 (snowfall) if colder than 2 C. This is made provided cloudines exceeds 6/8. In other case ww is put to 02 (no precipitation).

6). Precipitation has been assigned at a three-hourly basis based on the oberved (or completed) ww and the total amount at 06 or 18 UTC. Thus, if ww indicates heavy rainfall., then a large amount is assigned. The values are scaled to add up to the total observed amount. SMHI standard codes for assigning rainfall and snowfall have been used.

7). Air pressure is used in the psychrometric parameter and is given the latest available value. Since values at sea level are reported, air pressure is reduced to the elevation of the SYNOP station by 1 Hpa for each 8 m of elevation.

Interpolation is made to "0" only in the combinations: 11101, 11011, 10111, 11001, 10101, 10011 and 10001. For other combinations in one or more variables, no interpolation is made and the input for that occasion is put out unchanged. Then there are missing data which cannot be treated by the evapotranspiration model. For such an occasion the evapotranspiration model gives no three-hourly printout and no contribution to the monthly evapotranspiration sums. The monthly number of such three-hourly occasions are printed in the listing of the monthly output from the evapotranspiration model.

3. Evapotranspiration model.

The basis is the Penman-Monteith equation (Monteith 1965):

$$LE = \frac{\Delta(R_n - G) + \rho c_p (e_s(T) - e) / r_a}{\Delta + \gamma(1 + r_s / r_a)}$$

The first term is an energy term, where R_n is net radiation flux and G flux to heat storage in soil and vegetation cover. R_n is calculated from total cloudiness, solar elevation, wind speed and temperature by a statistical study of Nielsen et al. (1981), used also by Gardelin and Lindström (1997).

The second term may be called the ventilation term and describes how fast the water vapour is transported away.

r_a is the aerodynamical resistance between the surface and a reference or measuring level. $e_s(T)$-e, the vapour pressure deficit, is the difference between saturation vapour pressure at temperature T and the current vapour pressure e, both at the reference level. e is the saturation pressure for the dew point temperature. ρ is the density of air and c_p is the heat capacity of air.

r_s is the surface resistance.

Δ is the derivative of saturation vapour pressure with respect to temperature $=de_s/dT$.

γ is the psychrometric parameter = $c_p p/L\varepsilon$ where L is the latent heat of vaporization, p is air pressure and ε is a constant =0.622 equal to the ratio of molecular weights of water vapour and dry air. Evapotranspiration has been calculated for open land and for forest.

Based on Arpege Climat (1996) parameters for the ISBA model (see below) are given for nine landuse types for open land: crop, short grass, tall grass, tundra, irrigated crop, semi-desert, bog and marsh, evergreen shrub and deciduous shrub. For forest there are five landuse classes: evergreen needle tree, deciduous needle tree, deciduous broadleaf tree, evergreen broadleaf tree and mixed woodland.

The parameter values of Table 3 used in this study, are for open land those of crop (with some modifiaction) and for forest those of mixed woodland. As can be seen, some seasonal variation is allowed for forest in leaf area index and roughness length.

Table 3. Parameters used in the ISBA model. For forest surface, values of leaf area index and roughness length are given for each month.

	1: Open land	2: Forest
Leaf area index (LAI)	1.0	3.0, 3.0, 3.0, 4.0, 4.5, 5.0, 5.0, 5.0, 4.0, 3.0, 3.0, 3.0
Roughness length (m)	0.05	0.690, 0.717, 0.745, 0.763, 0.782, 0.800, 0.800, 0.772, 0.763, 0.745, 0.717, 0.690
Albedo for snow-free surface	0.20	0.16
Albedo for snow-covered surface	0.50	0.30
Vegetation canopy storage capacity of intercepted rain water (w_{max}, mm)	0.2*LAI	0.2*LAI
D:o of intercepted snow (w_{smax}, mm)	10*w_{max}	10*w_{max}
(w_{smax} is not in ISBA model, see the text)		
For calculating surface resistance (ISBA):		
RGL (for global radiation) (W m^{-2})	100	30
r_{smin} (s m^{-1})	40	250
α (for vapour pressure deficit)	0	0.04

3.1 Surface resistance r_s.

This resistance is caused by the action of the stomata pores of dry transpiring vegetation and is here calculated by the ISBA model using global radiation, vapour pressure, air temperature and soil moisture (Noilhan and Planton 1989). For wet surfaces and snow surfaces r_s is often put to zero. In winter and at night with no stomatal activity, dry surfaces have a large value of r_s: 5000 s m^{-1} is used in the ISBA model.

r_s, the surface resistance for transpiration, is given by:

$$r_s = \frac{r_{s\min}}{LAI} F_1 F_2^{-1} F_3^{-1} F_4^{-1}$$

LAI is leaf area index and r_{smin} is a reference surface resistance for each landuse type.

F_1 achieves a decreasing r_s with increasing photosyntetically active radiation R_G by:

$$F_1 = \frac{1+f}{r_{s\min}/5000+f}$$

$$f = 0.55 \frac{R_G}{R_{GL}} \frac{2}{LAI}$$

where R_{GL} is 30 W m^{-2} for forest and 100 W m^{-2} for low vegetation. 5000 s m^{-1} is the maximum value possible for r_{smin}.

F_2 gives the effect of water stress in the root zone, so that r_s increases when w_2 decreases:

$$F_2 = \frac{w_2 - w_{wilt}}{w_{fc} - w_{wilt}}$$

For w_2 larger than w_{fc}, F_2 is unity. For w_2 smaller than w_{wilt}, F_2 is assigned a very small value, giving a large r_s.

F_3 causes increasing r_s with increasing saturation deficit of specific humidity q (kg/kg):

$$F_3 = 1 - \alpha(q_{sat}(T_a) - q_a)$$

where α is 0.04 for forest and zero for low vegetation.

F_4 gives smallest surface resistance at 25 C increasing to the maximum value 5000 s m^{-1} below 0 C and above 50 C:

$$F_4 = 1 - \left(\frac{25 - T_a}{25} \right)^2$$

3.2 Aerodynamical resistance r_a.

r_a generally is calculated by a method used for an air pollution model developed at SMHI (Omstedt 1984). In principle, r_a is obtained by equalling r_a calculated by two different methods as function of the Monin-Obukhov length L_{mo}, an atmospheric stability parameter. r_a is solved by an iterative method described by Berkowics and Prahm (1982).

Method 1. Using wind and temperature profiles. Friction velocity u_* and aerodynamic resistance r_a are calculated as:

$$u_* = \frac{ku(z_u)}{\ln((z_u + z_o)/z_o) - \psi_m((z_u + z_o)/L_{mo}) + \psi_m(z_o/L_{mo})}$$

$$r_a = \frac{\ln((z_t + z_o)/z_o) - \psi_h((z_t + z_o)/L_{mo}) + \psi_h(z_o/L_{mo})}{(k/R)u_*}$$

z_u, and z_t are the measuring heights of wind speed and temperature respectively. z_u = 10 m and z_t = 1.5 m at most SYNOP stations. $u(z_u)$ is wind speed measured at height z_u.

Observed wind at 10 m over forest is smaller due to the larger roughness length. Since SYNOP stations report from open land surfaces, the wind speed for application for forest is reduced by

$$u_{10ratio} = \frac{\ln(100 / z_{0openland}) \ln(z \;\; / z_{0forest})}{\ln(100 / z_{0forest}) \ln(z \;\; / z_{0openland})}$$

assuming neutral conditions and that wind speed at height 100 m is the same over both forest and open land.

ψ_h and ψ_m are empirical stability functions dependent on L_{mo}. They are zero at neutral stability i. e. when L_{mo} is infinitely large. R is 0.74 and the value used of the von Karman constant is k=0.35.

Method 2. Using the counterpart of the Penman-Monteith equation for sensible heat flux H, with values of r_s, vapour pressure deficit $e_s(T)$-e and net radiation flux R_n:

$$H = \frac{(R_n - G)(r_s + r_a) - \rho c_p (e_s(T) - e) / \gamma}{r_s + (1 + \Delta / \gamma) r_a + \alpha (r_s + r_a)}$$

or

$$r_a = \frac{r_s (R_n - H) - \rho c_p (e_s(T) - e) / \gamma}{H(1 + \Delta / \gamma + 2\alpha) - R_n}$$

where α=G/H assumed to be 1/3. This was considered valid for a grass surface but is used here generally in this formula to calculate r_a. The sensible heat flux H is calculated from

$$H = -\frac{T}{gk} \frac{\rho c_p u_*^3}{L_{mo}}$$

u_* is calculated by the method described above. T is temperature in degrees K. g is the acceleration of gravity.

3.3 Rainfall interception.

Rainfall interception is treated for both low vegetation and forest. The interception reservoir w, on the canopy evolves as (Rutter et al. 1971/1972):

$$\frac{dw}{dt} = -\frac{w}{w_{\max}} \quad E_p$$

where E_p is the "potential" evaporation rate of the water on the vegetation canopy (mm / 3 hours) calculated with the Penman-Monteith equation using current meteorological data and r_s = 0. w_{max} is the storage capacity in mm.

The solution for the water stored at the end of the three-hour period, w_{3h}, is

$$w_{3h} = w_0 * \exp(-\frac{E_p}{w_{\max}}) + rr$$

where the three-hourly rainfall amount rr is added to the water stored after reduction of the initial storage w_0 by the evaporation during the three hours.

The excess water is throughfall to the ground:

$$thr = \max(0, w_{3h} - w_{\max})$$

and the remaining stored water, used as input w_0 to the next three-hour period, is

$$w_{3h} = \min(w_{3h}, w_{\max})$$

3.4 Transpiration.

The Penman-Monteith equation is used. Transpiration is calculated at the beginning and at the end of each three-hourly period and the average (in mm/ 3 hours) is formed. This holds for the dry vegetation canopy.

The transpiration from the partly wet vegetation canopy during the three-hourly period is reduced by the three-hour average part of the canopy covered with water obtained from the interception routine above:

$$(1 - 0.5\frac{w_0 + w_{3h}}{w_{\max}})$$

A completely wet canopy then gives zero transpiration.

3.5 Snow evaporation.

Due to practical reasons for the use in the HBV model, evaporation for snow free land and snow covered land are both calculated and presented in parallel, whether a real snow cover exists or not. Both evaporation components are calculated for open land as well as for forest. For both snow covered open land and forest, the Penman-Monteith equation is used with r_s = 0 and the snow albedo value of Table 3. The method is described in Appendix 1.

3.6 Feedback from the soil moisture accounting routine of the HBV model.

To get feedback, soil moisture is updated every three-hour time step in the evapotranspiration model, using the soil moisture accounting routine of the HBV model (Lindström et al. 1996). The routine calculates how much of the rainfall or snow melt that goes to runoff and how much is used to increase soil moisture. This partition is governed by the runoff coefficient BETA. The soil moisture accounting routine is only needed when soil moisture is used for getting evapotranspiration. This is the case here, since soil moisture is used in the factor F_2 above in calculating r_s. The parameters used are shown in Table 4.

Table 4. Parameters used in the soil moisture accounting routine of the HBV model for the six SYNOP stations studied.

FC: field capacity (mm).

BETA: runoff coefficient.

cfmax: degree-day factor for snow melt rate (mm C^1 day^{-1}).

	FC	BETA	cfmax-open land	cfmax-forest
Målilla, Nässjö	300	3.0	3.0	1.8
Osby, Ljungby	300	3.0	3.0	1.8
Fränsta, Hunge	180	2.0	3.5	2.0

3.7 Reduction of soil moisture by evapotranspiration.

After the update of soil moisture by the soil moisture accounting routine of the HBV model, soil moisture is reduced three-hourly by subtracting the sum of transpiration and interception evaporation. This is made if temperature exceeds 0 C and if snow depth is less than 0.1 mm (water equivalent).

4. Model output.

Before running the interpolation program the following months with no SYNOP data were replaced by the corresponding month from the neighbouring station:

Ljungby 8005 8006 8406 8407 8507 8508 by Osby
Osby 7407 7508 7708 7806 7808 7906 8603 8608 by Ljungby
Målilla 8806 by Nässjö
Nässjö 8606 8608 by Målilla
Hunge 8607 by Fränsta

After this replacement some data were still missing. Thus, in the whole period treated, 1968 - 1993, some months are not completly covered with three-hourly evapotranspiration values. In Osby there are 9 months with at least 25 missing three-hourly values, in Ljungby 11 months, Målilla 0, Nässjö 7, Fränsta 0 and Hunge 18 months. Thus, these months may have too low evapotranspiration values by more than some 10 per cent. In Hunge there are scarce data during 1992. The reduced values for these periods should be kept in mind when studying Figures 1 - 6. In running the HBV model using three-hourly data, these missing data have to be replaced by other data.

4.1 Three-hourly model output.

The primary model output is three-hourly evapotranspiration values calculated from the input SYNOP observations. These values are used as input to the HBV model. The three-hourly output is given and described for the two surface types open land and forest in Table 5.

Table 5. Example of a three-hourly data output from the evapotranspiration model. For each surface type (1 and 2) the data are given as 19 groups including the identification "datout". The group numbers attached here are explained below. The values of evapotranspiration (No. 8, 9, 10, 11 and 12), throughfall (No. 15) and precipitation (No. 17) for e. g. 18 hrs UTC are three-hourly sums over the period 15 hrs UTC to 18 hrs UTC. Values No. 7, 13, 14, 16, 18 and 19 refer to time indicated (here 18 UTC).

1	2	3	4	5	6	7	8	9	10	11	12
datout	1	68	6	29	18	1	0.67882	0.00000	0.44351	0.44351	0.44668

13	14	15	16	17	18	19
15.20000	0.20000	1.01000	0.00000	1.21000	164.518	0.00000

```
   1     2   3   4    5    6  7      8            9            10           11           12
 datout  2  68   6   29   18  1  1.20425  0.00000  0.34738  0.34738  0.01591
15.20000  1.00000  0.21000  0.00000  1.21000  193.946  0.00000
   13          14          15           16          17         18          19
```

1: Identification
2: Surface type
3: Year
4: Month
5: Day
6: Hour UTC
7: State of the ground surface in the SYNOP observation (E)
8: Potential evapotranspiration by the Penman-Monteith equation using $r_s = 0$ (mm/3 hours)
9: Evaporation of rainfall intercepted on the vegetation canopy (mm/3 hours)
10: Transpiration from dry part of canopy (mm/3 hours)
11: Sum of 9 and 10: total evapotranspiration (snow free conditions) (mm/3 hours)
12: Evaporation from existent or nonexistent snow cover (mm/3 hours)
13: Observed air temperature (C)
14: Water stored on vegetation canopy (mm)
15: Throughfall (mm/3 hours)
16: Snow stored on forest canopy (mm water equivalent)
17: Reported precipitation multiplied with 1.1 (mm/3 hours)
18: Calculated soil moisture (mm)
19: Calculated snow depth (mm water equivalent)

4.2 Monthly model output.

To give an overview of the results, monthly sums of the evapotranspiration components have been produced. These values are given in tables (not shown) with data described below. Also, precipitation, soil moisture and the number of missing three-hourly data are given.

Description of data in the monthly model output:

Station number of SYNOP station used.
Year.
Month.
A figure where 1 means open land and 2 means forest.

The following six values are monthly sums in mm of

1 - Evaporation of rainfall intercepted on the vegetation canopy.
2 - Transpiration from dry part of canopy.
3 - The sum of 1. and 2., i. e. total evapotranspiration (snow free conditions).
4 - Evaporation from snow cover.
5 - Calculated actual total evapotranspiration summed from each three-hourly observation: (3.) used in snow-free conditions and (4.) used if snow cover occurs.
6 - Measured monthly precipitation in mm (corrected by multplication with 1.1)
7 - Soil moisture in mm.

8 - Number of missing three-hourly observation occasions during the month.

The monthly outputs for 1968-1993 and all six SYNOP stations are plotted in Figures 1 - 6 based on the tables. Some months may have too low sums due to missing data.

5. Discussion of monthly evapotranspiration data.

Figures 1 - 6 show calculated monthly evapotranspiration sums for 1968 - 1993. In summer, the transpiration sums (2.) are greater for open land than for forest, an effect of the larger surface resistance used for forest. However, forest gives higher interception evaporation (1.) than open land, due to larger canopy water storage capacity of forest. Since the transpiration difference is greater than the interception difference, the total evapotranspiration (3.) is mostly greater for open land than for forest. There is some indication also in monthly data, that transpiration is small when evaporation of intercepted rainfall is large, which is given three-hourly by the model as described above.

Due to practical reasons, snow evaporation (4.) is always calculated, whether a real snow cover exists or not. In summer, the formal snow evaporation curves for open land show the "potential" evapotranspiration, but using an increased albedo value due to the snow surface.

In winter, the forest snow evaporation (4.) is often larger than for open land, due to the larger evaporation flux from intercepted snow on the forest canopy. In the northerly stations Hunge and Fränsta, negative snow evaporation occurs for open land in some winters, due to the negative contribution of the radiation term in the Penman-Monteith equation.

Lowest in Figures 1 - 6 is the "actual" evapotranspiration chosen from the "snow free" curve (3.) or "snow" curve (4.), judged to be "actual" as to whether snow depth is greater or smaller than 15 mm of water respectively, obtained from the soil moisture accounting routine of the HBV model, in the run made here. 15 mm is a high limit giving "snow free" very often, and therefore we see that the curves (5.) are similar to those of "snow free" (3.) not only in summer but also a large part of many winter seasons. In some winters and early springs (e g Målilla in 1979), it is seen that the actual values (5.) are taken from the snow case however. The "actual" curve is coinciding with or between the "snow" and "snow free" curves because we present monthly values summed from three-hourly values.

What will be used in the HBV model are three-hourly values of total snow free evapotranspiration (No. 11 in Table 5) or snow evaporation (No. 12) dependent on whether there is snow or not. This will be determined using the snow cover of the complete HBV model.

In Figure 7, a comparison is made with actual evapotranspiration computed using the HBV model (Brandt and Grahn 1998). Evapotranspiration and runoff are given by standard functions (soil moisture accounting routine) in the HBV model. In the different geographical areas considered, the values of the parameters in these functions are tuned, so that the resulting runoff comes in best agreement with measured runoff data. The evapotranspiration then comes out as a "water balance estimate" within the HBV model framework.

The HBV model values are mostly between our evapotranspiration model values for open land and forest, a reasonable result, since the former are derived over areas surrounding the SYNOP stations. The soil moisture values behave very similarly in both models, since they are both calculated by similar functions, but are smaller than those modelled in the evapotranspiration model, because smaller values of field capacity were used. The comparison has been made with the whole material 1968 - 90 (except for Hunge) and the comparison as a whole, was similar to that of Figure 7. This comparison is of limited value since both methods use the soil moisture accounting routine. Other parts of the data are different, such as SYNOP weather observations for the evapotranspiration model and runoff data for the HBV model.

Coming work.

The evapotranspiration model should be tested against directly measured evapotranspiration values, e. g. in the NOPEX project. This may lead to improvements of the evapotranspiration model. For example, at the main NOPEX site (Norunda) it has recently been found that the evaporation of intercepted water from the forest canopy is not as quick as believed previously (A. Lindroth pers. comm.). This may happen if the water is concentrated into small droplets on the leaves and needles. This should be studied and may give rise to modification of the present model. Another important problem is the influence of soil moisture on transpiration rate from vegetation. Other modifications of the evapotranspiration model will probably be made after the coming runs of the HBV model using the present calculated evapotranspiration values.

Acknowledgements.

Marie Gardelin (SMHI), who was the project leader, informed how to design the results to make them useful for the HBV model, specified the parameter values of the soil moisture accounting routine and plotted Figures 1 - 6. Gunnar Omstedt (SMHI) supplied the code to calculate basic meteorological parameters. Christina Lindgren (SMHI) supplied prepared SYNOP data, performed the runs of the evapotranspiration model and stored the data for later use in the HBV model. Hans Alexandersson (SMHI) and Hans Bergström (MIUU) supplied the temperature and dew point temperature correction data from Uppsala Airport. Anders Lindroth (SLU) supplied winter evaporation data from Norunda in the NOPEX area. Maja Brandt and Gun Grahn (SMHI) supplied HBV model data for the locations studied.

Appendix 1. Development of the snow evaporation model.

Due to practical reasons for the use in the HBV model, evaporation for snow free land and snow covered land are both calculated and presented in parallel, whether a real snow cover exists or not. Both evaporation components are calculated for open land as well as for forest. In both snow covered open land and forest, the Penman-Monteith equation is used with $r_s = 0$ and snow albedo of Table 3.

Forest.

For forest a snow interception model has been developed. This was considered worthwhile, since the evaporation of snow on the forest canopy is much more rapid than the evaporation of snow on the forest floor.

Daily evaporation values for the winter half year 1 Oct. 1994 - 31 March 1995 measured in the Norunda mast by the eddy correlation method have been compared with different model results. SYNOP observations from Uppsala Airport have been used as model input.

Since comparison is made with real evaporation data, which are taken over snow free or snow covered terrain, there must be an assumption as to whether snow exists or not and the model value presented must be the one calculated for that assumption. The forest terrain was assumed snow covered if $E > 4$ where E is the SYNOP code describing the state of the ground surface.

Regarding that a snow cover cannot be warmer than 0 C, the Penman-Monteith equation was tested assuming reference temperature $T = 0$ C in cases with higher observed temperatures. However, allowing $T > 0$ C showed better agreement with the Norunda daily measured data. The reason is probably that the snow cover in forest terrain is not uniform and there are often surfaces warmer than 0 C. Therefore, the temperature values have been used without maximizing to 0 C.

The following snow interception algorithm was used for the forest canopy:

With e_{can} - snow evaporation from the forest canopy in mm/3 hours; w_{sn} - snow amount on the canopy in mm of water (maximized to w_{smax}) and rr_{snow} - snowfall in mm/3hours the following calculations are made in order:

$w_{sn} = w_{sn} - \min(w_{sn}, e_{can})$
$w_{sn} = w_{sn} + rr_{snow}$
$w_{sn} = \min(w_{sn}, w_{smax})$

If air temperature exceeds 2 C, w_{sn} is reduced by 50% every three-hours period. w_{smax} is the storage capacity for snow on the forest canopy (mm of water). Following Calder (1990), this capacity is assumed to be ten times as large as that of intercepted rain water (Table 3). Snow throughfall is not considered since the snow on forest floor is not budgeted.

Using the above assumptions, and r_a = constant was found to give better agreement with eddy correlation snow evaporation data from the Norunda forest than using wind and stability dependent r_a values. A reason may be that the wind speed variation at Uppsala airport is probably larger than over the Norunda forest. Also, the distance to Norunda is some 22 km making the use of the Uppsala wind data more difficult. In the model, r_a is used as constant corresponding to a wind speeed of 1.8 m/s at the roughness length value of Table 3. For the snow case, snow was always assumed to exist on the forest floor. Then, snow evaporation is low since r_a is increased by the factor $(1+ 1.08*LAI)$ accounting for the resistance of the canopy air. Net radiation is reduced by the factor $(1-0.2*LAI)$. Tuning the model to evaporation measurements should be made using model input data from the Norunda site itself. Also, a better judgement if the forest canopy is snow covered or snow free should be made, using direct observations at the Norunda forest. Therefore, this model development is only preliminary.

Open land.

This model is similar to the forest model but no snow interception algorithm is used. It was found that the model parameters for open land gives better agreement, than the forest model, to the daily Norunda forest evaporation data. The SYNOP data are taken at an open field (Uppsala Airport). Maybe they should not be used together with parameter values (albedo, roughness) representing a forest. Such model input data, which could differ between forest and open land are precipitation, cloudiness, temperature and vapour pressure deficit - all important for the evaporation. Therefore, the agreement could be better using albedo and roughness for open land as found here.

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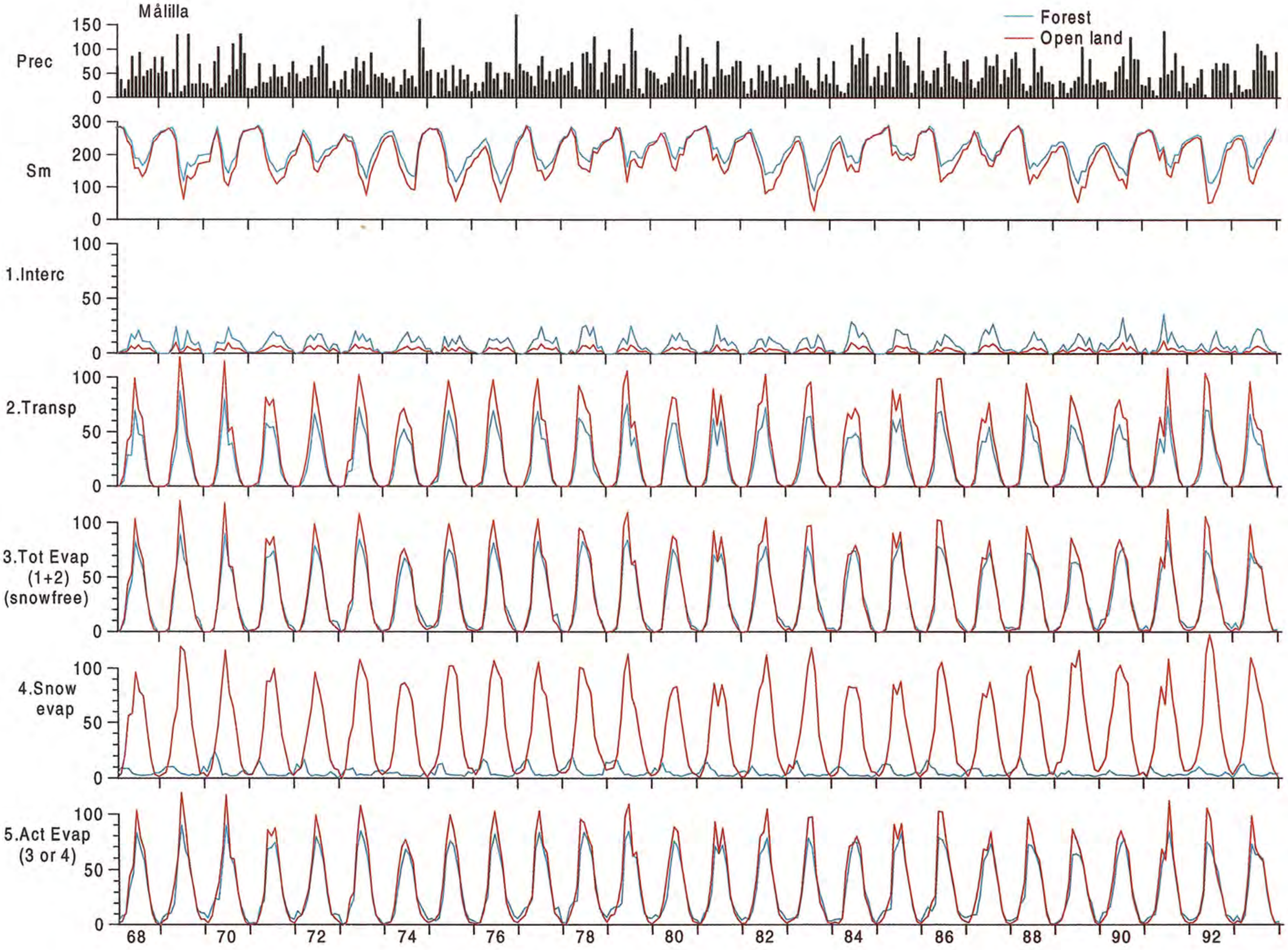
Figures 1 - 6. Monthly precipitation, soil moisture and evapotranspiration sums (mm) derived from three-hourly SYNOP data during 1968-1993. Evapotranspiration components (1. - 5.) and soil moisture are calculated with the evapotranspiration model and the soil moisture accounting routine of the HBV model.

Prec	Measured monthly precipitation in mm (corrected by multplication with 1.1)
Sm	Soil moisture in mm.
1. Interc	Evaporation of rainfall intercepted on the vegetation canopy.
2. Transp	Transpiration from dry part of canopy.
3. Tot Evap	The sum of 1. and 2. i. e. total evapotranspiration (snow free conditions).
4. Snow evap	Evaporation from snow cover.
5. Act evap	Calculated actual total evapotranspiration summed from each three-hourly observation: (3.) used in snow free conditions; (4.) used if snow cover occurs.


Målilla
Forest
Open land
Prec
Sm
1.Interc
2.Transp
3.Tot Evap (1+2) (snowfree)
4.Snow evap
5.Act Evap (3 or 4)
68
70
72
74
76
78
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82
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86
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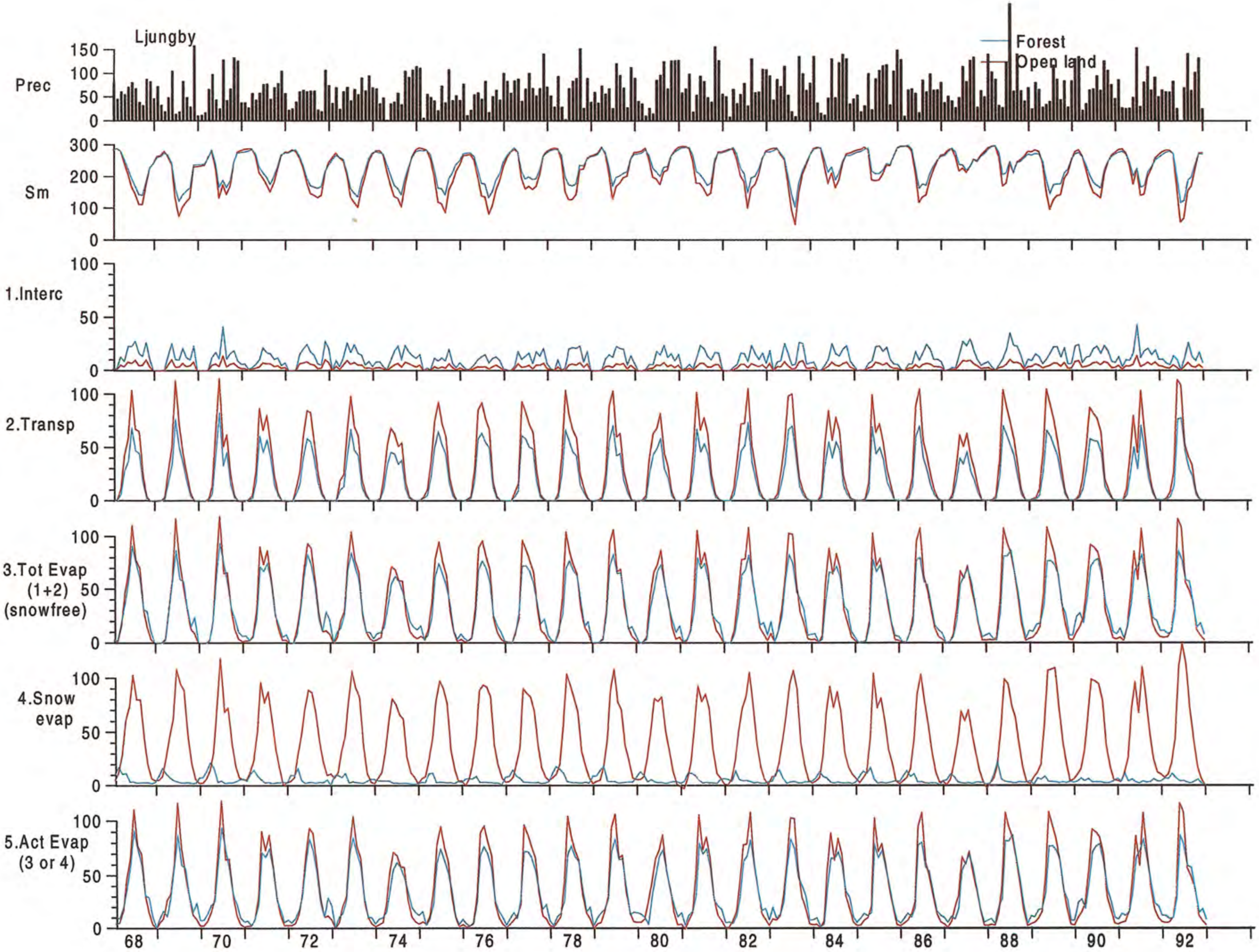
Ljungby
Forest
Open land
Prec
Sm
1.Interc
2.Transp
3.Tot Evap (1+2) (snowfree)
4.Snow evap
5.Act Evap (3 or 4)
150
100
50
0
300
200
100
68
70
72
74
76
78
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84
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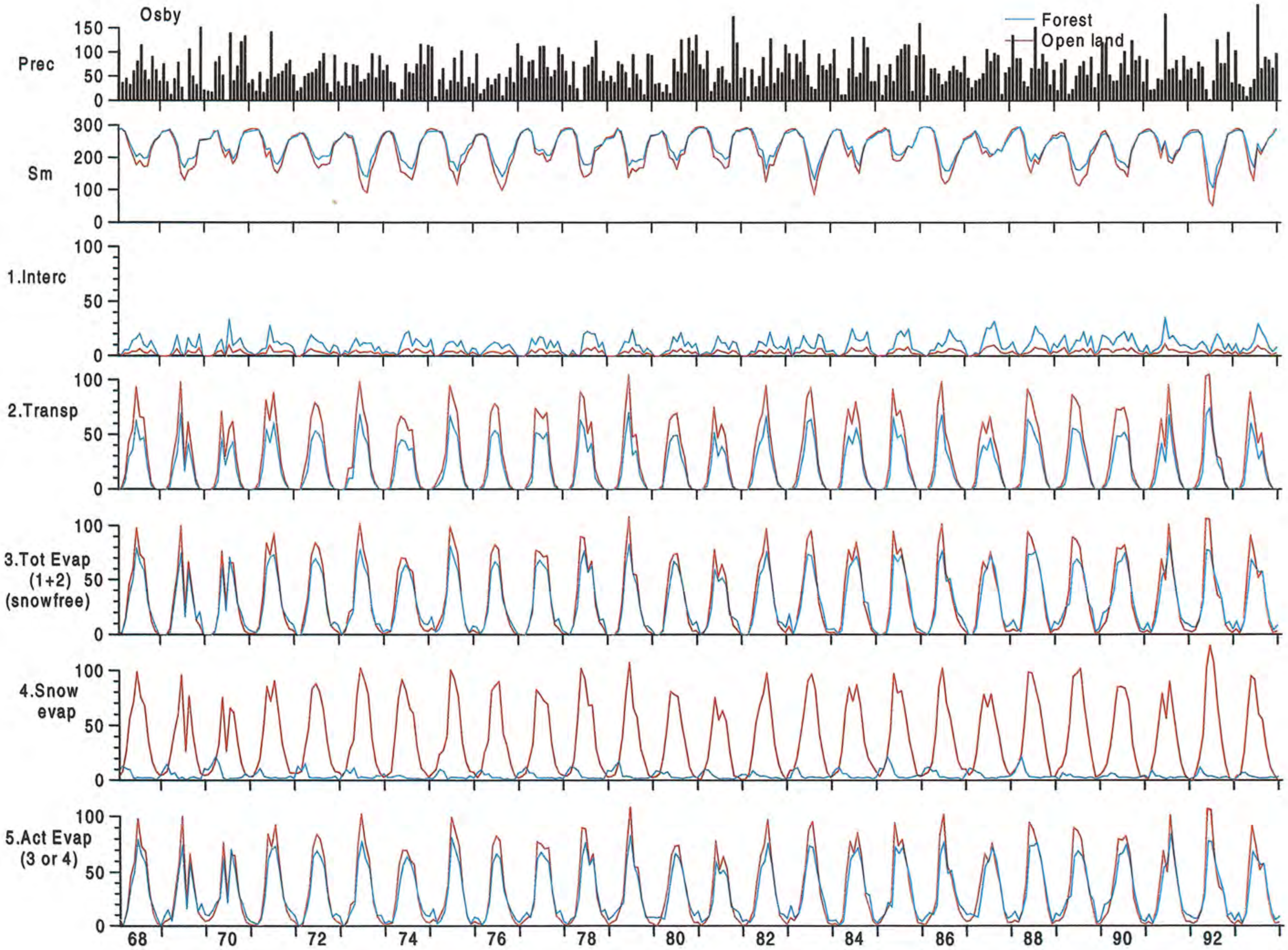
Osby
Forest
Open land
Prec
150
100
50
0
Sm
300
200
100
0
1.Interc
100
50
0
2.Transp
100
50
0
3.Tot Evap
(1+2)
(snowfree)
100
50
0
4.Snow
evap
100
50
0
5.Act Evap
(3 or 4)
100
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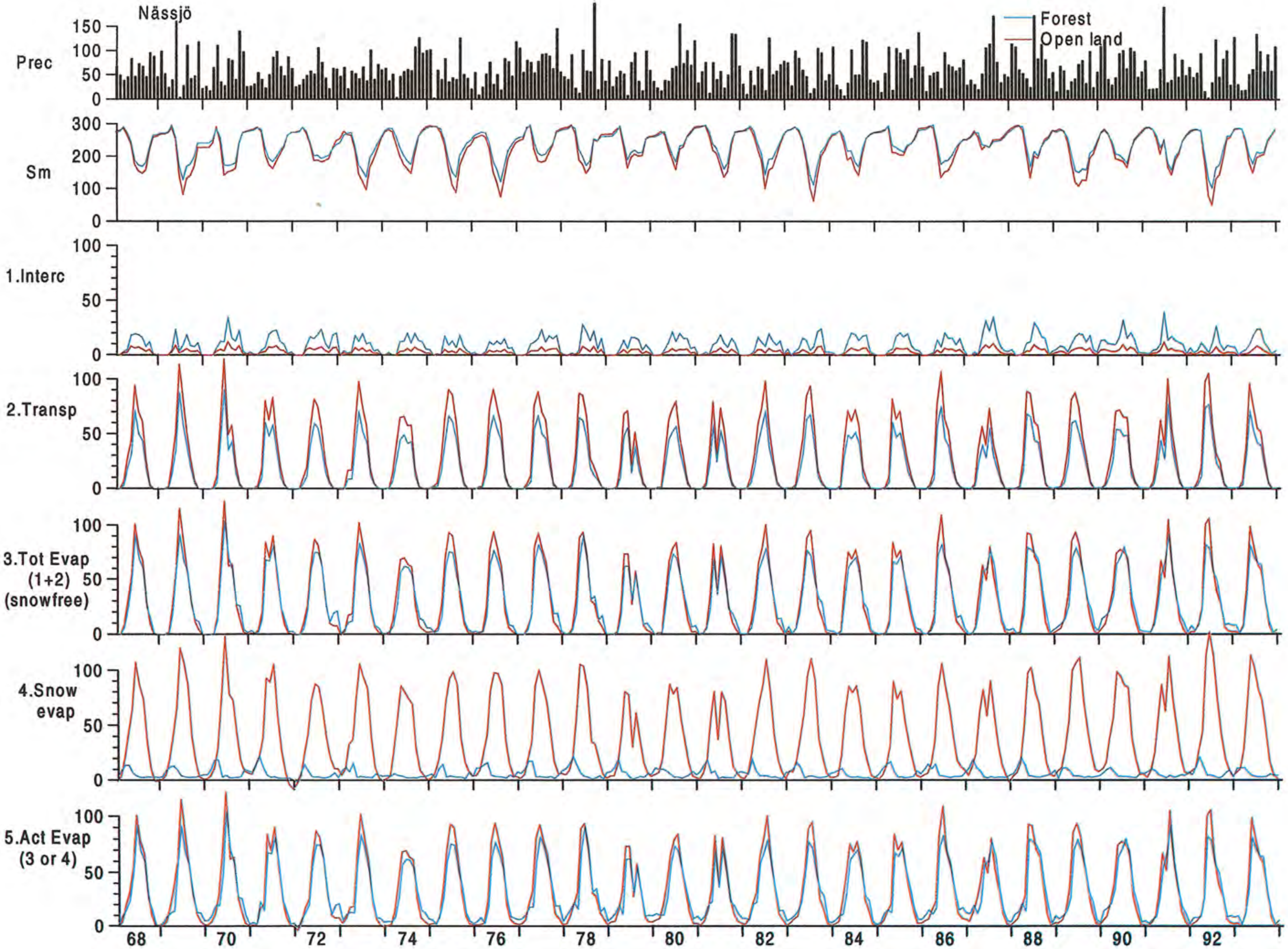

Nässjö
Forest
Open land
Prec
Sm
1.Interc
2.Transp
3.Tot Evap (1+2) (snowfree)
4.Snow evap
5.Act Evap (3 or 4)
68
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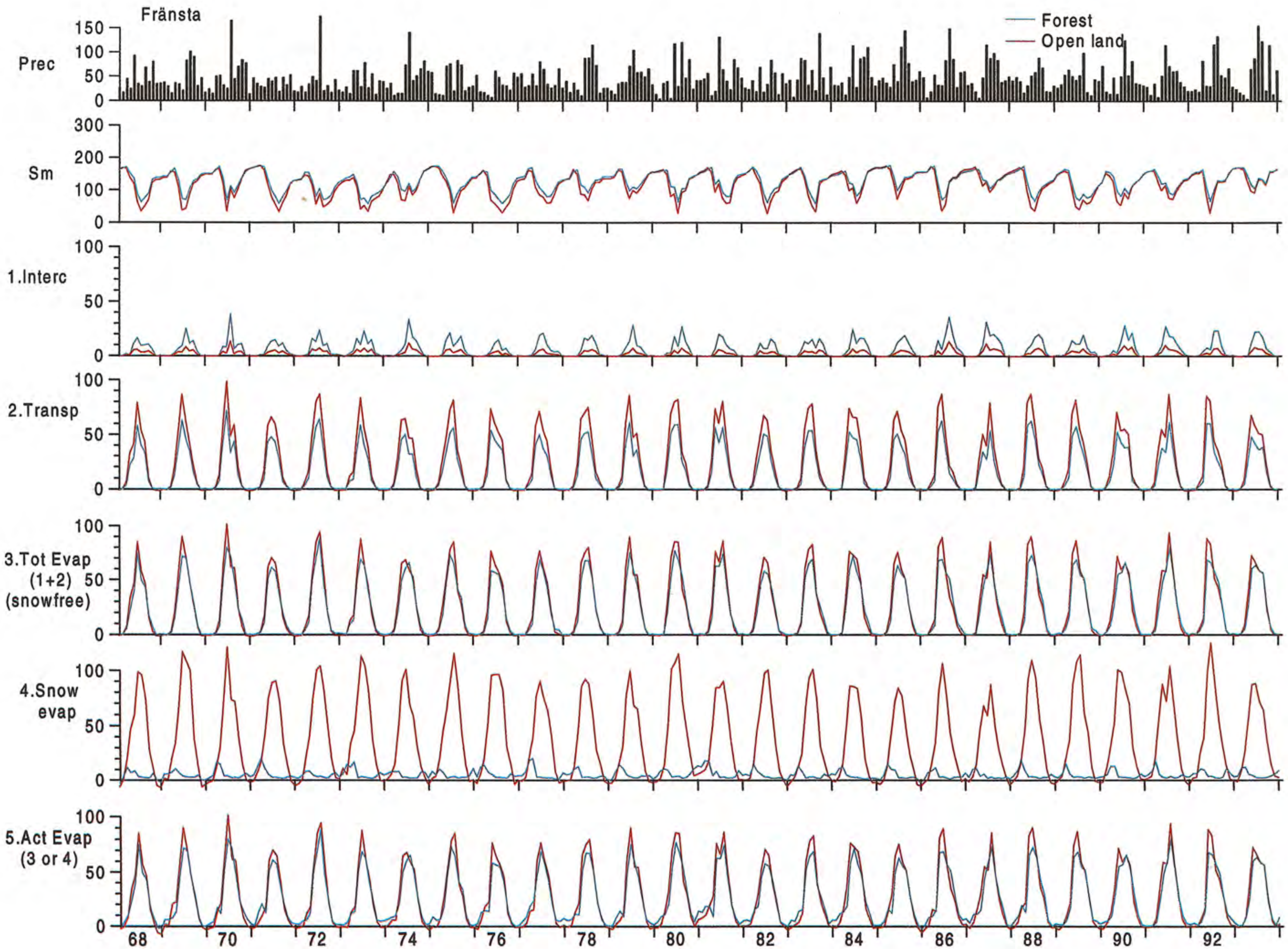
Fränsta
Forest
Open land
Prec
150
100
50
0
Sm
300
200
100
0
1.Interc
100
50
0
2.Transp
100
50
0
3.Tot Evap
(1+2)
(snowfree)
100
50
0
4.Snow
evap
100
50
0
5.Act Evap
(3 or 4)
100
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68
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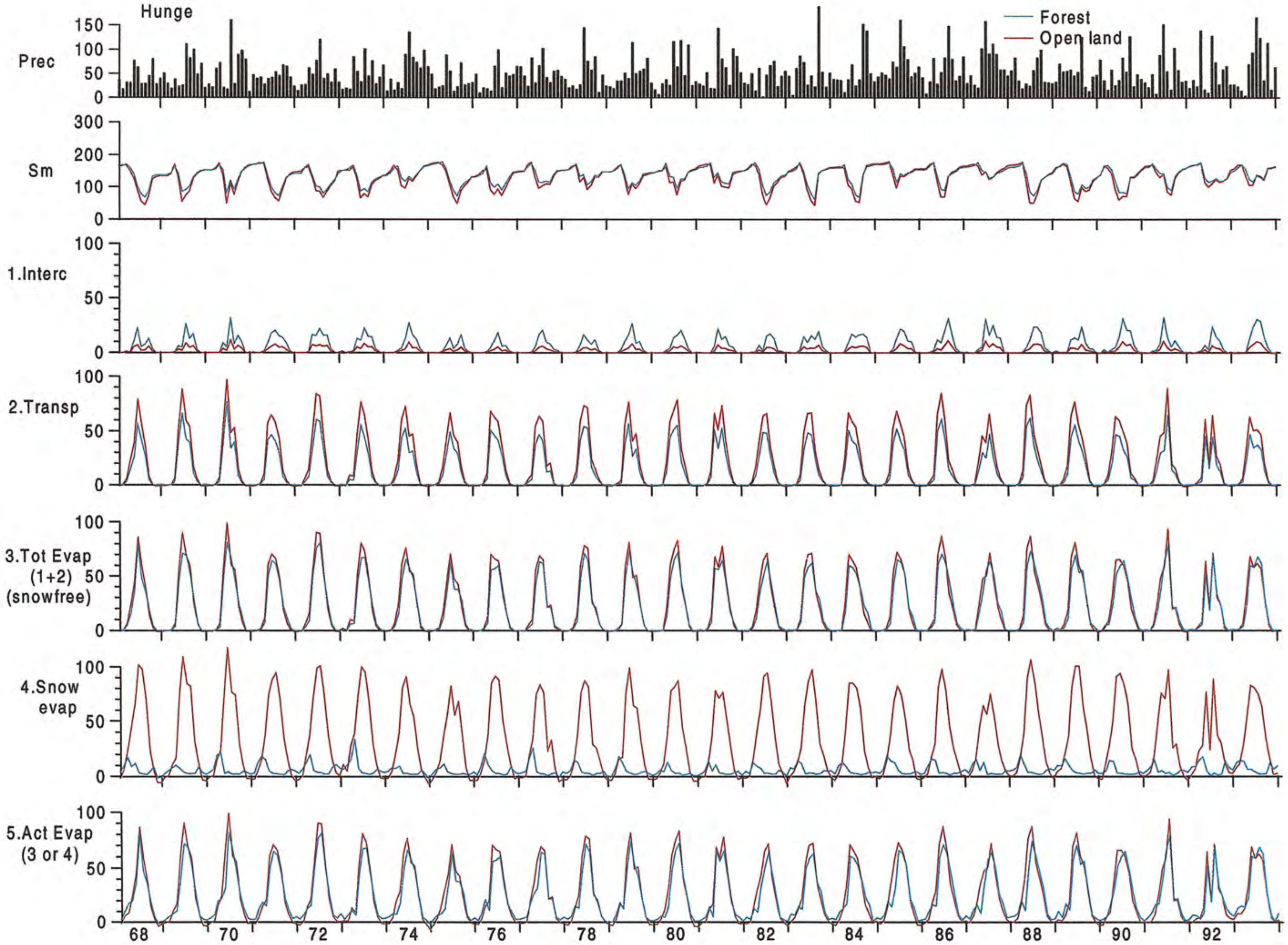
Hunge
Forest
Open land
Prec
150
100
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Sm
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1.Interc
100
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2.Transp
100
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3.Tot Evap
(1+2)
(snowfree)
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0
4.Snow
evap
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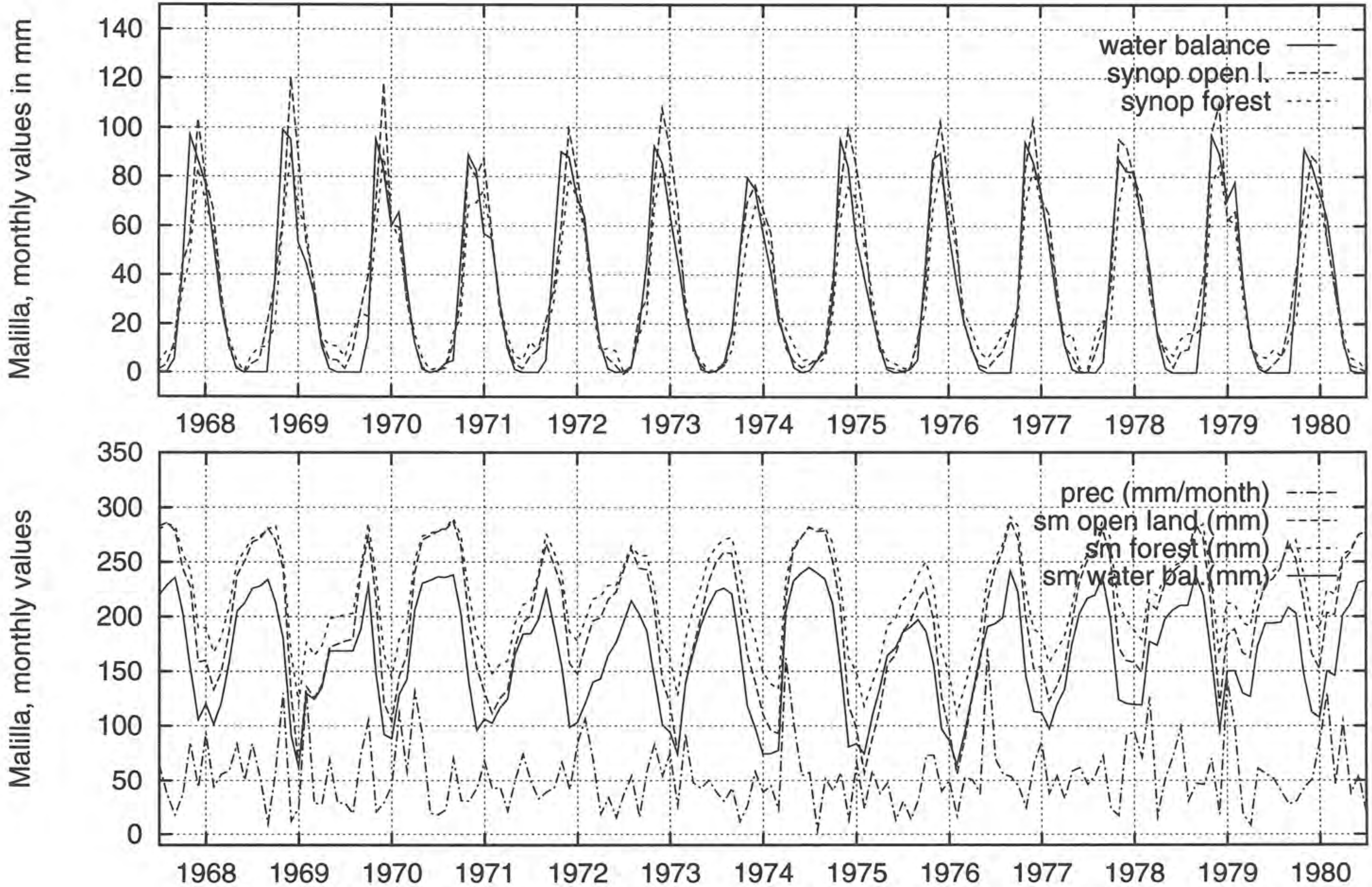

Figure 7a. Målilla 1968-1980. The upper part gives monthly evapotranspiration values by the evapotranspiration model for open land and forest (hatched curves) and by the water balance method+HBV model (solid curve). The lower part gives the curves for soil moisture and, at the bottom, measured precipitation.

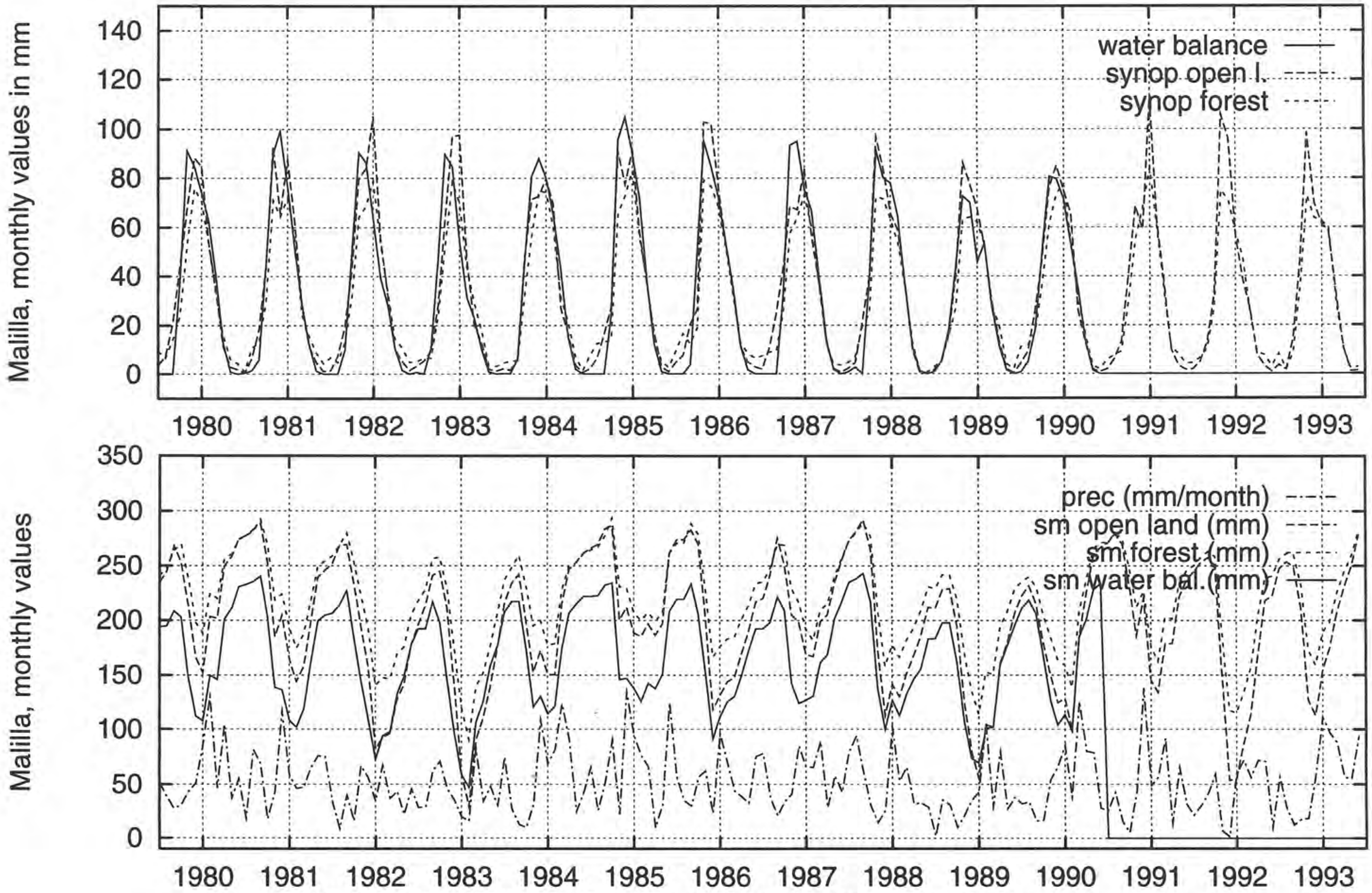

Figure 7b. Målilla 1980-1993. The upper part gives monthly evapotranspiration values by the evapotranspiration model for open land and forest (hatched curves) and by the water balance method+HBV model (solid curve). The lower part gives the curves for soil moisture and, at the bottom, measured precipitation.

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