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Energy and Water Balances of a Bog in Central Sweden

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Fens and bogs represent a considerable part of the boreal forest area of Scandinavia, but have not received much attention. To understand their role in the water and energy balances an investigation was carried out during the spring and summer of 1994 as a part of the NOPEX program. Groundwater level, precipitation and energy budget parameters were measured at the Ryggmossen bog, 35 km Northwest of Uppsala. The evaporation (10 min averages) was determined by the Energy Balance Bowen Ratio method and a reference evaporation (10 min averages) was also calculated according to Penman (1948). The results of the evaporation and energy balance study showed that the actual evaporation was 60% of the reference evaporation and that the evaporation rate was dependent on the groundwater depth. The weather during the period was warm with extremely low precipitation. The evaporation therefore decreased during the summer in response to the increased depth to the groundwater table. A relation was found between the groundwater level recession rate and the evaporation rate. The albedo increased during the summer and any occasional decrease could be attributed to individual rain storms.

Introduction

Mires represent a considerable part of the Swedish land area, about 16% excluding mires in the alpine areas and cultivated mires (Stenbeck 1985). This means that they play an important role in the water balance and for the land surface energy balance.

Projects within **NOPEX**, Northern Hemisphere Climate Processes Land-Surface Experiment, are studying the fluxes and dynamics of the interchange of momentum, water, heat and carbon dioxide between the land surface and the atmosphere. The experiment is conducted in an 50×100 km^2 area in central Sweden. The area is a moraine landscape covered by thin layers of soil above the crystalline bedrock. Thick moraine clay and bare bedrock also occur. The area is situated in the centre of a part of northern Europe where the boreal forest is common (Lundin and Halldin 1994).

Mires are different from other types of land covers in many aspects, *e.g.* their high heat insulating ability, high water keeping ability and low soil roughness length. The purpose of this project was to quantify the dynamics of and the interaction between the energy balance and water balance of a mire. Measurements of evaporation, groundwater level and precipitation were conducted on the Ryggmossen bog during the summer of 1994.

Site Description

Ryggmossen is a high moor situated approximately 30 km NW of Uppsala, *i.e.* 17°20'E, 60°02'N. The rim around the bog is overgrown with stunted pine and mire brushwood while the central parts are open with some short stunted pines. The diameter of the central plane is about 600 m. Outside the rim of the bog there is an untouched, *i.e.* unditched lag where the dominant vegetation type is of so called sedge-Sphagnum. Further outside the lag there is coniferous forest towards the north, east and south. Due west the dominant vegetation type is wooded marsh, birch, pine and spruce on ditched mire ground. The height of the woods around the bog is at most 15-20 m.

Methods of Measuring and Computing

Measurements of radiation were conducted between 23 May and 30 August 1994. The long-wave component of the net radiation was measured approximately 1 m above the ground with a 8111 Ph.Schenk instrument. Because of different calibration factors for short-wave and long-wave radiation the instrument was only used for measurement of the long-wave component. The short-wave components, *i.e.* global radiation and reflected short-wave radiation, were measured at the same location and level by using two CM5 Kipp & Zonen instruments.

The net radiation was determined according to

$$R_n = \left(U_{Rn(\mathrm{Ph.Schenk})} - \frac{S_{n(\mathrm{Kipp\&Zonen})}}{K_{Sw}} k_{Lw}\right) + S_{n(\mathrm{Kipp\&Zonen})} \tag{1}$$

$U_{Rn(Ph.Schenk)}$ is the voltage in mV that is received from the Ph.Schenk instrument, it has a linear relationship to the net radiation. $S_{n(Kipp\&Zonen)}$ is the net shortwave radiation measured by the Kipp & Zonen instruments.

The calibration factors, k_{S_w} and k_{L_w} for the short and long-wave band of the Ph. Schenk instrument, respectively, were determined by comparisons with instruments calibrated at Swedish Meteorological and Hydrological Institute (SMHI). The radiation fluxes were measured every 10 seconds and stored as 10-minute means.

The daily average albedo was computed from the stored 10-minute mean values of the radiation. The albedo was calculated only for the times when the sun was 20° or more above the horizon. This was done to minimize errors due to uncertainties of the radiation instruments at low sun angles.

The ground-heat flux was determined by using four heat-flux plates (Middleton CN3). The heat-flux plates were placed one centimetre below the soil surface, at the same site as the radiation instruments. The error due to the storage of heat between the soil surface and the top of the heat-flux plates was assumed to be negligible compared with the errors due to the other parameters in the energy balance equation. The soil heat-flux G, was computed as the mean value of the results from the four heat-flux plates. The measured mean voltage was multiplied by the manufacturers calibration factor of the heat-flux plates (= 65 $\mathrm{W/m^2mV}$).

The evaporation was computed by using the Energy Balance Bowen Ratio method (EBBR) (Brutsaert 1982)

$$E = \frac{(R_n - G)}{L_e(1+Bo)} \tag{2}$$

The Bowen ratio is defined as the ratio between the vertical sensible heat flow H and the latent heat flow $L_e E$ in the atmospheric boundary layer

$$Bo = \frac{H}{L_e E} \tag{3}$$

A TIS (Thermometer Interchange System) was used in order to determine the necessary parameters for computing the evaporation according to EBBR (Lindroth and Halldin 1990). Dry and wet air temperature are measured with Pt-100 instruments at the 1.1, 2.12 and 3.12 metre levels above the peat surface. The time constants of the instruments are approximately 15 s. The Pt-100 instruments change their relative positions every 5 minutes in order to minimize the systematically errors that can occur when using several Pt-100 instruments at stationary levels. The air humidity was determined by the psychrometer method.

Evaporation according to Penman (1948) was determined for a comparison of the actual evaporation. Penman's method is often used to calculate evaporation from mires (Brandyk 1985; Gilvear *et al.* 1993; Roulet 1991). The following formula is valid for all wet surfaces (Rosenberg *et al.* 1983). The net radiation above a water surface R_{no}, is replaced with the net radiation above and the heat storage in the ground, $(R_n + G)$

$$E_{\mathrm{ref}} = \frac{\Delta(R_n+G)+\gamma E_A}{\Delta+\gamma} \tag{4}$$

$$E_A = 0.26(1+0.54\bar{u}_2)(e_e-e_a)$$

$E_A = 0.26\,(1+0.54\bar{u}_2)(e_s-e_a)$ where $\bar{u}_2$ is wind speed (m/s) measured at 2 m height as a supplement to the data from TIS. The wind speed was determined by four-cup anemometers. The anemometers could not record values below 2 m/s.

The groundwater level in the bog was measured manually several times each week at a groundwater tube situated near by the TIS.

No runoff measurements were made at Ryggmossen but the presence of existing runoff was observed continuously.

Measurements of groundwater level from the Trappmossen mire, situated 10 km SW from the Ryggmossen bog, was used in order to study the evaporation rate relative to the diminishing groundwater level during the dry period in July. The groundwater level at Trappmossen was measured continually with a pressure transducer, and these measurements were used in order to study the relation with a higher time resolution (Pettersson and Phersson 1994). The data (15-minute mean values) from Trappmossen were used under the assumption that the evaporation rates from the two mires were almost equal. This was assumed because the mires have very similar ground water depths during the dry period.

Accumulated precipitation was measured with a SMHI-rain gauge two to three times a week during the period 1 June to 5 September 1994.

Results

The daily evaporation, based on 10-minute estimated evaporation values, varied as shown in Fig. 1.

The evaporation (mm/10 min) according to Penman's formula was only calculated for three days in July when the wind speed exceeded the anemometers initial velocity, 2 m/s. The average ratio E/E_{penman} was estimated to 0.6 (Fig 2.).

In situ calibration of the heat flux plates was estimated to

$$G = 67.2U_{mvp} - 13.5\ \mathrm{W/m^2}\ (R^2 = 0.67) \tag{5a}$$

when the peat was dried out and

$$G = 126.8U_{mvp} - 0{,}1\ \mathrm{W/m^2}\ (R^2 = 0.88) \tag{5b}$$

under wet conditions, U_{mvp} is the volt reading from the plates. The net radiation inaccuracy was approximately 6 W/m^2 (Halldin and Lindroth 1992).

The average albedo increased from approximately 0.12 in the beginning of the growing season to 0.22 when the peat had almost dried out (Fig. 3). The average was estimated to 0.17 ± 0.03.

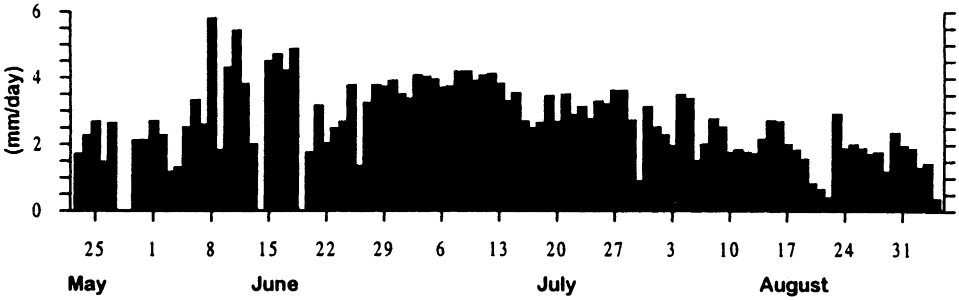

Fig. 1. Evaporation (mm/day) Ryggmossen 1994. Values are missing during a few days in June when the instruments were out of order.

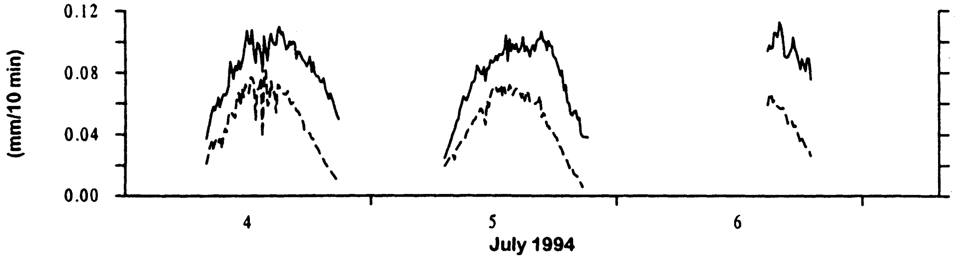

Fig. 2. Evaporation (mm/10 min) due to Penman (1948), continuos line and to EBBR, dashed line at Ryggmossen for three days in July 1994.

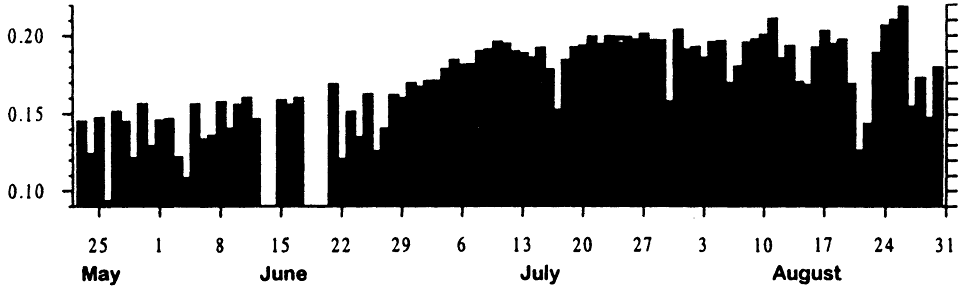

Fig. 3. Daily average albedo, Ryggmossen 1994.

The groundwater table depth in Ryggmossen was fluctuating between 6 and 25 cm below the surface (Fig. 4). The groundwater table depth in Trappmossen fluctuated between 3 and 35 cm during the same period. This, together with the fact that the vegetation on these two mires is the same, confirms the transfer of data between the two sites.

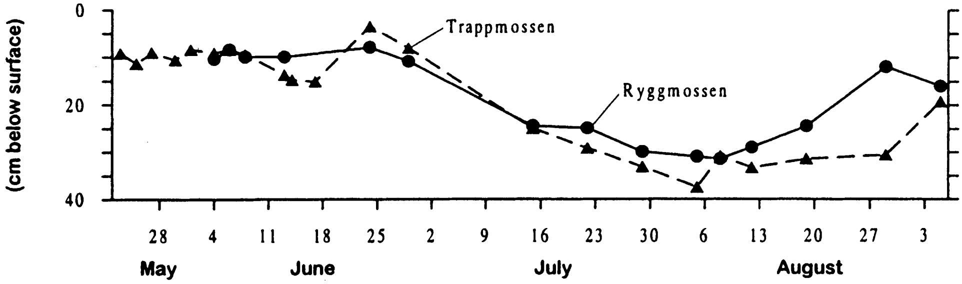

Fig. 4. Groundwater depth (cm), Ryggmossen and Trappmossen 1994.

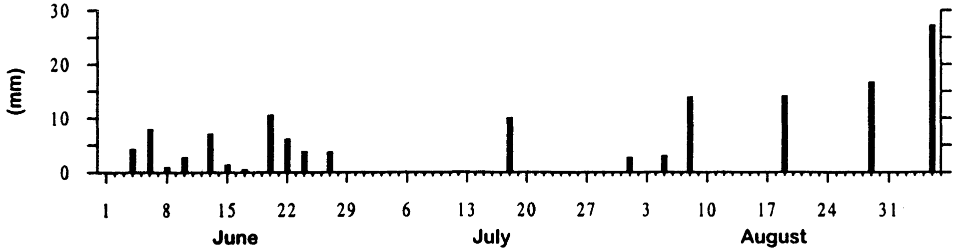

Fig. 5. Precipitation (mm), Ryggmossen 1994.

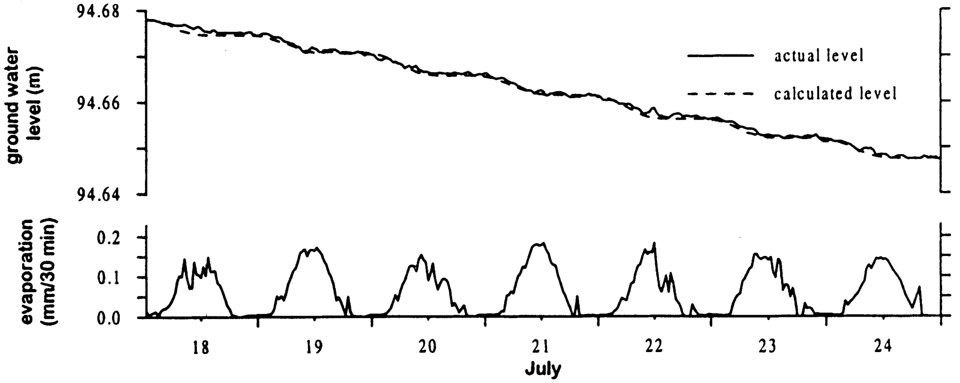

Fig. 6. Actual and calculated groundwater level (m), Trappmossen and evaporation (mm/30 min), Ryggmossen a week in July 1994.

Daily precipitation totals at Ryggmossen are presented in Fig. 5. The accumulated precipitation of the period, 1 June- 5 Sept., was 130.5 mm at the Ryggmossen site and 126.7 mm at the Trappmossen site.

Half hourly evaporation totals (mm/30 min) estimated at Ryggmossen was related to the groundwater level data (m) obtained at 30 minutes intervals at Trappmossen.

An empirical relationship was found between rate of change in groundwater level and evaporation rate. During the 28 day period with only one precipitation event and no measurable runoff in July, parts presented in Fig. 6., it is given by

$$H_t = H_{t-0.5} - 1.65 E_{t-19} \quad (R^2 = 1.00) \tag{6}$$

H_t is groundwater level height at time t, $H_{t\text{-}0.5}$ is groundwater level height at time t-0.5 hours and $E_{t\text{-}19}$ is evaporation rate at time t-19 hours.

Discussion and Conclusions

The amount of evaporable water in May and June was large due to significant precipitation and considerable snow storage. This led to high evaporation for the hot days in June. Almost no precipitation occurred during the extremely hot weeks in July, the groundwater table decreased continually and the evaporable amount of water decreased during the period. This is an effect of the decrease in peat conductivity when the peat dries out (Lafleur and Roulet 1992). The precipitation in August caused a rapid increase of the groundwater table because of the dry peat. As an effect of this and because the temperature also became higher the evaporation started to increase in the middle of August.

Earlier research (Ingram 1983; Lafleur and Roulet 1992) shows that bog evaporation and Penman evaporation are almost equal. Values on the E/E_{penman} ratio between 1 and 1.1 for treeless bogs and around 1.4 for fens is reported (Ingram 1983). Ingram thus proclaims that summertime measurements point out that $E<E_{\text{penman}}$ for treeless bogs. The same results is reported from other summer investigations (Lafleur and Roulet 1992). This investigation gives a value around 0.6. The difference between actual and Penman evaporation varies during the day because of the evaporation of early morning dew and the fact that the ratio E/E_{penman} depends on the saturation deficit. This drying effect will be larger if the windspeed increases. If nighttime values also where available this drying effect may not be that important when calculating the daily average ratio.

A calibration factor of 65 W/m^{2}mV was used to calculate the soil heat flux. *In situ* calibration (Eqs. (5 a) and (5 b)) shows the same value under dry peat conditions while under wet conditions the value raises about 100%, probably as an effect of the fact that the plates are designed for mineral soil where the variation in water content is small. The constant factor obtained can be explained partly as an effect of the heat storage in the thin soil layer between the plates and the surface. The minus sign of the constant term refers to the data set that only contains data from evening or night time when heat is lost from the surface. The constant factor is not negligible under dry conditions.

The albedo (Fig. 3) is highest during the summer which reflects a drying process due to insufficient water resources. Similar results are shown earlier (Ingram 1983).

Individual rainfall events appear as a sink of the albedo and is not to be seen as a recovery of the vegetation but as the result of water on the peat surface. The albedo of water is low and the water evaporates fast which gives a fast return to almost the same albedo as before.

Further analysis of the albedo investigation can verify a general use of these albedo values. This implies that net radiation,both the long-wave and the short-wave components, can be estimated with a simple net radiation instrument, global radiation from a nearby station and albedo values over the bog.

The groundwater level fluctuations of Ryggmossen and Trappmossen during the period is shown in Fig. 4. Evaporation from bogs is expected to depend on the depth of the groundwater table (Lafleur and Roulet 1992). Comparison of the slopes of the curves in the same figure at a time when there is no inflow, outflow or precipitation shows that the slopes are similar. The divergence between 18 and 25 of July is due to one single rainfall at Ryggmossen when there was no precipitation at all at Trappmossen. The period 9-18 August with no precipitation at Ryggmossen is not considered in Eq. (6) because there were several days with precipitation in Trappmossen. The change in peat water content did not receive any attention, but as the vegetation on these two mires is the same it is assumed that the upper peat layers also are equal. This implies that the arguments in comparing groundwater data from Trappmossen with evaporation data from Ryggmossen are fully supported.

The fact that the groundwater table response lags as much as 19 hours behind evaporation can be explained by the relatively large depth to the groundwater surface. The time-lag decreases during periods with more shallow groundwater, but at these occasions both precipitation and runoff are present.

If more general conclusions for peatlands are to be made, periods with more climatological variation than the one used in this study are needed. The study will be repeated at Stormossen (Mellander *et al.* 1996).

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