Growing season variability of net ecosystem CO\textsubscript{2} exchange and evapotranspiration of a sphagnum mire in the broad-leaved forest zone of European Russia

A Olchev\textsuperscript{1,4}, E Volkova\textsuperscript{2}, T Karataeva\textsuperscript{2} and E Novenko\textsuperscript{3}

\textsuperscript{1} A N Severtsov Institute of Ecology and Evolution of RAS, Leninskiy Prospekt 33, 119071 Moscow, Russia
\textsuperscript{2} Tula State University, Lenin Prospekt 92, 300012 Tula, Russia
\textsuperscript{3} Institute of Geography of RAS, Staromonetniy Pereulok 29, 119017 Moscow, Russia
\textsuperscript{4} Russian State Agrarian University—Moscow Timiryazev Agricultural Academy, Timiryazevskaya Street 49, 127550 Moscow, Russia
E-mail: aoltche@gmail.com

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Abstract

The spatial and temporal variability of net ecosystem exchange (NEE) of CO\textsubscript{2} and evapotranspiration (ET) of a karst-hole sphagnum peat mire situated at the boundary between broad-leaved and forest–steppe zones in the central part of European Russia in the Tula region was described using results from field measurements. NEE and ET were measured using a portable measuring system consisting of a transparent ventilated chamber combined with an infrared CO\textsubscript{2}/H\textsubscript{2}O analyzer, LI-840A (Li-Cor, USA) along a transect from the southern peripheral part of the mire to its center under sunny clear-sky weather conditions in the period from May to September of 2012 and in May 2013. The results of the field measurements showed significant spatial and temporal variability of NEE and ET that was mainly influenced by incoming solar radiation and ground water level. The seasonal patterns of NEE and ET within the mire were quite different. During the entire growing season the central part of the mire was a sink of CO\textsubscript{2} for the atmosphere. NEE reached maximal values in June–July ($-6.8 \pm 4.2$ $\mu$mol m\textsuperscript{-2} s\textsuperscript{-1}). The southern peripheral part of the mire, due to strong shading by the surrounding forest, was a sink of CO\textsubscript{2} for the atmosphere in June–July only. ET reached maximal values in the well-lighted central parts of the mire in May (0.34 $\pm$ 0.20 mm h\textsuperscript{-1}) mainly because of high air and surface temperatures and the very wet upper peat horizon and sphagnum moss. Herbaceous species made the maximum contribution to the total gross primary production (GPP) in both the central and the peripheral parts of the mire. The contribution of sphagnum to the total GPP of these plant communities was relatively small and ranged on sunny days of July–August from $-1.1 \pm 1.1$ mgC g\textsuperscript{-1} of dry weight (DW) per hour in the peripheral zone of the mire to $-0.6 \pm 0.2$ mgC g\textsuperscript{-1} DW h\textsuperscript{-1} at the mire center. The sphagnum layer made the maximum contribution to total ET at the mire center (0.25 $\pm$ 0.10 mm h\textsuperscript{-1}) and the herbaceous species on the peripheral part of the mire (0.03 $\pm$ 0.03 mm h\textsuperscript{-1}).

Keywords: net CO\textsubscript{2} exchange, gross primary production, evapotranspiration, sphagnum mire, mire plant communities, sphagnum moss, chamber flux measurements
1. Introduction

The modern changes of climatic conditions that are mainly characterized by the increase of global temperature and change of moisture conditions can obviously have significant impacts on all processes in the biosphere (IPCC 2007). They influence the sustainable development of different vegetation types and can be either favorable for growth of plant communities or can lead to their dying. The vegetation feedback on climate is manifested through multiple pathways, primarily by changing the energy, water, and greenhouse gas balance of the atmosphere (Chapin et al. 2008). How different plant communities affect the climate system and what their sensitivity is to changing environmental conditions is not yet completely investigated. Clearly, this task needs further experimental and theoretical studies.

Mires cover only about 2% of the global land area. However, they accumulate a large amount of organic carbon in peat deposits (Gorham 1991, Minaeva et al. 2008, Keddy 2010) and can obviously have significant impacts on the global CO$_2$ cycle. Moreover, mire ecosystems are able to retain water incoming as precipitation and surface runoff and therefore influence the surface hydrological regime. The dynamics of organic carbon in mires is determined mainly by the balance between CO$_2$ absorption by the mire vegetation during the photosynthesis process, and CO$_2$ emission caused by plant respiration and decomposition of organic substances in the peat soil. Information about CO$_2$ and H$_2$O fluxes between various types of mire ecosystems and the atmosphere are necessary, on the one hand, to define the role of different types of mires in atmospheric CO$_2$ and H$_2$O cycles, and on the other hand, to assess the mire production and intensity of paludification.

Within the framework of the present experimental study, the CO$_2$ and H$_2$O exchange processes were described for a typical sphagnum mire situated at the boundary of the broad-leaved forest and forest–steppe zones of European Russia (figure 1). This boundary area is represented by a complex mosaic of different plant ecosystems including forest and agricultural area, grassland and mires. During the last three decades most experimental studies of CO$_2$ and H$_2$O exchange in the forest–steppe zone have been focused on agricultural crops and grasslands (Vygodskaya et al. 1998, Belelli Marchesini et al. 2007). The role of mires in the regional CO$_2$ and H$_2$O budgets has not yet been investigated sufficiently. Experimental studies of CO$_2$ and H$_2$O fluxes in mire ecosystems in Northern Eurasia were mainly reported for sub-arctic and boreal forest areas of Russia (e.g. Arneth et al. 2002, Zamolodchikov et al. 2003, Kurbatova et al. 2002, 2009, Marushchak et al. 2013) and North Europe (Johansson et al. 2006, Nilsson et al. 2008, Carter et al. 2012).

2. Experimental site and field measurements

The experimental area is situated in the Tula region at the watershed of the upper Don, Upa and Oka rivers. The hilly relief, with elevation ranging between 200 and 300 m a.s.l., is mainly composed of erosional landforms. The climate of the area is temperate moderately continental with mean annual temperature of 4.4°C and annual precipitation about 520 mm (www.meteo.ru/data/). Vegetation is mainly represented by grasslands with large blocks of broad-leaved forests and embedded mires of different types. The unique character of the region is characterized by the very high diversity of mire types distinguished by geomorphological position (inundated, ravine, terrace and watershed mires), and water and mineral supply (eutrophic, oligotrophic, mesotrophic) (Volkova 2010, 2012). The watershed mires usually have a relatively small size (0.1–10 ha) and are characterized by high diversity in vegetation, depth of peat deposits and the degree of paludification. Many watershed mires in the area were formed in karst relief forms. The karst mires originate in the funnel-shaped karst depressions (sinkholes) which are formed through the processes of dissolution of limestone in bedrock by groundwater. Usually such karst depressions are comparatively deep (10 m depth or more) and have a round or elliptical surface shape. Eutrophic vegetation is typical for mires with complete peat deposits and for young floating mires. Meso- and oligotrophic plant communities are typical for mires with float peat deposits only.

To study the NEE and ET of a watershed mire within the study area the floating karst-hole peat mire ‘Glavnoe’ (54.06°N, 37.59°E, 260 m a.s.l.) located close to the village of Ozerniy in the Tula region was selected (figure 1). The area of the mire is about 1.2 ha and it is a typical peat mire according to water and mineral supply as well as to

Figure 1. Map of vegetation zones in central European Russia and the geographical location of the experimental site (marked by a white square). Legend: 1—southern taiga, 2—coniferous and broad-leaved forest zone, 3—broad-leaved forest zone, 4—forest–steppe zone, 5—steppe zone.
vegetation composition. The mire was formed in several karst-hole depressions. The average depth of peat deposits is about 5–6 m and in some parts of the mire it exceeds 10 m. The vegetation structure of the mire is very heterogeneous (figure 2). The vegetation of the peripheral parts of the mire is typical eutrophic whereas its vegetation in its central part is represented by meso–oligotrophic plant species. The growing season in the study region begins in April and ends in October when the mean daily temperature drops below 4–5 °C.

To describe the temporal and spatial patterns of NEE and ET fluxes within the selected sphagnum peat mire, 5 key experimental plots (2 m × 2 m) were chosen, situated along a transect from the southern peripheral zone of the mire to the center (figure 2). Two experimental plots (1–2) were selected in the peripheral part of the mire and three plots (3–5) in its central part. The southern part of the mire that was selected is characterized by maximum species diversity and the full range plant communities found on the mire.

The eutrophic vegetation in the southern peripheral part of the mire consists of birch (Betula pubescens—12–15 m high), back bean (Menyanthes trifoliata), wood club rush (Scirpus sylvaticus), honeysweet (Filipendula ulmaria), marsh fern (Thelypteris palustris), marsh sedge (Carex rostrata) and sphagnum (Sphagnum riparium). Plot 1 is represented by the Betula pubescens and Menyanthes trifoliata plant community with Sphagnum (Bet–Men–Sph); and plot 2—the scarce Betula pubescens, Carex rostrata and Sphagnum (Bet–Cr–Sph). The peat deposits consist mainly of herb–and sedge–sphagnum peat (decomposition degree is 30–35%). Ground water level (WL) in the summer period of 2012 was relatively high and ranged between 8 and 22 cm depth. The content of oxygen in the mire water varied between 2.45 and 3.07 mg l⁻¹, pH was 5.5–5.7.

The central part of the mire is about 0.7 ha and it is characterized by meso–oligotrophic plant cover with white beak-sedge (Rhynchospora alba), sedges (Carex lasiocarpa, Carex rostrata), rannoch-rush (Scheuchzeria palustris), cranberry (Oxycoccus palustris) with sphagnum (Sphagnum angustifolium, S. fallax, S. magellanicum) and scarce birch (Betula pubescens) tussocks (the height of birch is up to 1–1.5 m). Plot 3 is represented by the Rhynchospora alba (Rh) and Carex rostrata (Cr) plant community with Scheuchzeria palustris and Sphagnum angustifolium, S. fallax; plot 4—Rh–Cr community with Oxycoccus palustris, Scheuchzeria palustris and Sphagnum magellanicum, S. angustifolium; and plot 5—Rh–Cr community with Scheuchzeria palustris and Sphagnum magellanicum, S. angustifolium. The float of the mire (2.5–3.0 m depth) consists mainly of cotton grass–sphagnum and sedge–sphagnum peat (decomposition degree is 15–20%). WL during the growing season of 2012 was also very high and changed from 5 to 17 cm depth. The content of oxygen in the mire water was 1.46–1.94 mg l⁻¹, pH—4.2–5.3.

The chamber method was used for measurements of NEE and ET fluxes because of small size of the mire, a very uniform surrounding forest stand and the mosaic mire vegetation. All these factors promote very heterogeneous turbulent flow conditions within the mire (Olchev et al 2009) and make it difficult to apply, for example, eddy covariance methods that are widely used for flux measurements in micrometeorology. These methods also require a relatively uniform upwind-fetch distance of at least about 100 times the instrument height above the plant canopy (Norman et al 1997).

The flux measurements were performed during the period from May to August 2012 and in May 2013. They were carried out in the form of intensive field campaigns during 2–5 days per month to prevent any damage of vegetation cover in the mire. To avoid any effect of varying solar irradiance on NEE and ET estimations the fluxes were measured under sunny cloudless or partly cloudless weather conditions only. The flux measurements performed in May 2013 were used to supplement the small data set obtained in May 2012. The weather conditions and vegetation structure during the periods of field measurements in May 2012 and 2013 were quite similar.

The system for flux measurements consisted of a transparent ventilated chamber (0.4 m × 0.4 m × 0.2 m) combined with a portable infrared CO₂/H₂O analyzer LI-840A (Li-Cor, USA). Measurements of incoming photosynthetically active radiation (PAR), air and peat temperatures, air humidity and WL were obtained simultaneously with measurements of NEE and ET at each measuring plot along the transect. Incoming PAR was measured by a Q5 quartz sensor (Delta-T, USA). The measurements of air temperature and relative humidity were provided by a Testo 625 (Testo, Germany) thermo-hygrometer. An infrared thermometer Testo 830-T4 (Testo, Germany) was used to measure the surface temperature. Soil temperatures at depths of 5 and 10 cm were measured with Saviol mercury-filled angle thermometers.

The measurements were carried out within each measuring plot at 3–4 points. Each measuring procedure in
each point includes at least three measurements of NEE and ET under ambient light conditions and three measurements under artificial darkening of the chamber. The darkening was done using a completely non-transparent and light-reflecting cover to estimate dark respiration rate (RE). The mean duration of chamber darkening was about 10 min. To avoid any uncertainties in flux estimations due to superfluous increase in CO₂ and H₂O concentrations inside the chamber it was regularly ventilated by ambient air. GPP was estimated as the difference between measured NEE and RE.

To quantify the contribution of the individual plant groups, sphagnum moss and peat soil to total NEE and ET, several additional plots situated in the peripheral and central parts of the mire close to plots 1 and 4 were selected. These were characterized by similar species composition and structure. The method to estimate the flux partitioning among individual plant groups was based on determination of the difference between fluxes measured before and after removing (cutting) of corresponding plant groups from the plant community. To estimate the GPP of individual plant groups the measurements in each step were performed under ambient light and under dark conditions. The NEE, GPP and ET of sphagnum moss were measured after removing of all herbaceous and suffruticous species from the measuring plot. The measuring experiments were carried out under cloudless weather conditions in the daylight time from 11:00 to 16:00 in July–August 2012. The measuring program for plots 1 and 4 also included measurements of light response curves to describe the NEE and GPP patterns under different irradiance conditions. This was done by artificially shading the measuring chamber with a set of transparent covers and nets.

3. Results and discussion

The results of the experimental study showed significant spatial and temporal variability of NEE and ET along the transect from the peripheral to the central part of the peat mire. At the beginning of the growing season in May in the central part of the mire under clear-sky weather conditions NEE did not exceed $-2.6 \pm 0.6 \mu mol \cdot m^{-2} \cdot s^{-1}$ (at plot 5) despite very high PAR (up to $1400 \mu mol \cdot m^{-2} \cdot s^{-1}$) and high WL (9–12 cm depth). In the peripheral part of the mire at plot 1 NEE was positive (plant and soil respiration exceeded photosynthesis rate, and the plant community was a source of CO₂ for the atmosphere) and reached $2.7 \pm 0.9 \mu mol \cdot m^{-2} \cdot s^{-1}$. Very high values of incoming PAR (up to $1500–1600 \mu mol \cdot m^{-2} \cdot s^{-1}$) and a large amount of living biomass in June promoted maximal NEE of plant communities situated in the central part of the peat mire ($-5.8 \pm 0.5 \mu mol \cdot m^{-2} \cdot s^{-1}$ at plot 4 and $-6.8 \pm 4.2 \mu mol \cdot m^{-2} \cdot s^{-1}$ at plot 5) (figure 3). The mean value of NEE at plot 3 was about 1.5–2 times smaller than NEE at plots 4 and 5, mainly due to lower values of incoming PAR that did not exceed $700–900 \mu mol \cdot m^{-2} \cdot s^{-1}$ around noon. Plant communities in the peripheral eutrophic parts (plots 1 and 2) of the mire in June–July were characterized by slightly positive NEE in the morning and negative NEE (CO₂ sink) during short periods in the afternoon when the incoming PAR exceeded 100–150 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The maximal value of NEE there was observed in July ($-2.7 \pm 2.9 \mu mol \cdot m^{-2} \cdot s^{-1}$ at plot 1). The large variability of NEE within each experimental plot which is manifested even under equal incoming PAR, air and peat temperature conditions can be explained by a large diversity and heterogeneity of plant and Sphagnum cover, complexity of micro-relief, and non-uniform wetness of the sphagnum moss and upper peat layer.

The intensive overheating of plants and Sphagnum moss in the central part of the mire in August due to high incoming PAR (up to $1500 \mu mol \cdot m^{-2} \cdot s^{-1}$) and extremely high air temperatures reaching 33–38 °C in the afternoon were the main reasons for a decrease of plant photosynthesis, increase of plant respiration and the reduction of NEE (NEE ranged between $-3.1 \pm 2.9 \mu mol \cdot m^{-2} \cdot s^{-1}$ at plot 5 and $-4.2 \pm 2.7 \mu mol \cdot m^{-2} \cdot s^{-1}$ at plot 4). NEE at plot 3 was also much lower in June and July and did not exceed $-1.1 \pm 0.6 \mu mol \cdot m^{-2} \cdot s^{-1}$. The peripheral plots 1 and 2 were sources of CO₂ for the atmosphere over a whole day (NEE was $1.8 \pm 0.6 \mu mol \cdot m^{-2} \cdot s^{-1}$ at plot 1 and $2.1 \pm 1.0 \mu mol \cdot m^{-2} \cdot s^{-1}$ at plot 2, respectively) mainly due to high daily temperatures and strong shading by trees. The air temperature (at height of 2 m above ground) at these plots ranged between 25 and 29 °C in the period 10:00–16:00 h, and PAR did not exceed 150–200 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

The contribution of peat respiration to total NEE in August compared with June and July did not change.
significantly, mainly because of very small changes of peat temperatures (ranging between 19 and 21 °C at 5 cm depth). Low seasonal variability of peat temperatures can be explained by the very low heat conductivity and high heat capacity of sphagnum cover and peat (Heiskanen 2000, Schouwenaars and Gosen 2007).

In September, despite relatively warm weather conditions with air temperatures in the afternoon near 20–22 °C and incoming PAR in the central part of the mire of about 1200 μmol m⁻² s⁻¹ (maximum), NEE significantly decreased and for central plots 4 and 5 was −1.0 ± 1.9 and −0.4 ± 1.6 μmol m⁻² s⁻¹, respectively (figure 3). NEE at intermediate plots 2 and 3 was close to zero. The vegetation community at plot 1 was a CO₂ source for the atmosphere (NEE was about 1.1 ± 0.5 μmol m⁻² s⁻¹) in September, as well as throughout most of August, even in the afternoon. The decrease of NEE in September in comparison with summer months can be explained by several reasons, first of all, by reduction of the physiological and biochemical activity of the different plant species. Moreover, such a trend can also be explained by drying of some leaves of herbaceous species and thus some reduction of total photosynthesizing biomass of plants in the mire.

The seasonal pattern of RE was mainly influenced by air and vegetation temperature. In the central and peripheral parts of the mire maximal values of RE (6.4 ± 0.7 and 2.2 ± 1.1 μmol m⁻² s⁻¹, respectively) were observed in August, which was extremely warm.

The seasonal course of ET differed significantly from the seasonal pattern of NEE (figure 3). Maximal values of ET were observed in May (ET = 0.34 ± 0.20 mm h⁻¹) and can be explained by high daytime temperatures (up to 30 °C), high WL (9–12 cm) and the large amount of available water in the upper peat horizons.

In June–July WL declined to 14–17 cm and it can be considered as a main reason of the ET decrease both in the central (0.17 ± 0.09 mm h⁻¹ at plot 4 in July) and in the peripheral part (0.03 ± 0.02 mm h⁻¹ at plot 1 in July) of the mire. In August the air temperature in the area significantly increased reaching 33–38 °C at the open parts of the mire. WL did not change significantly and ranged between 14 and 15 cm. All these factors resulted in some increase of ET that reached in the central part of the mire 0.27 ± 0.09 mm h⁻¹ (at plot 4) and some decrease of ET in the peripheral part (0.01 ± 0.01 mm h⁻¹ at plot 1). In September ET in the central part did not exceed 0.046 ± 0.044 mm h⁻¹ and in the peripheral part it was close to zero.

The results of our experiments to determine the contribution of various plant groups and sphagnum moss to total GPP, RE and ET in plant communities situated close to plots 1 and 4 showed that the maximal contribution to GPP for both communities came from herb species. For the Bet–Men–Sph plant community near plot 1 situated at the peripheral zone of the mire the GPP of *Menyanthes trifoliata* and *Carex* species under very low values of incoming PAR (on average 50–150 μmol m⁻² s⁻¹ in the middle of the day) was about 6.1 ± 7.5 μmol m⁻² s⁻¹ (−3.9 ± 4.8 mg C g⁻¹ DW h⁻¹) (figure 4). GPP of herbaceous plants and *Oxyccoccus palustris* in the Rh–Cr–Sph plant community near plot 4 in the central part of the mire under much higher values of incoming PAR (up to 1200–1400 μmol m⁻² s⁻¹) was quite similar −5.9 ± 2.0 μmol m⁻² s⁻¹ (3.9 ± 1.3 mg C g⁻¹ DW h⁻¹) and −3.4 ± 2.1 μmol m⁻² s⁻¹ (2.2±1.3 mg C g⁻¹ DW h⁻¹), respectively (figure 4). The difference between GPP of *Sphagnum* species in both communities was also relatively small: GPP of the *Sphagnum riparium* in the Bet–Men–Sph plant community was 3.0 ± 2.9 μmol m⁻² s⁻¹ (1.1 ± 1.1 mg C g⁻¹ DW h⁻¹) and GPP of *Sphagnum magellanicum* and *S. angustifolium* in

Figure 4. Contribution of different plant groups and peat to GPP, RE and ET for the Bet–Men–Sph (plot 1) and Rh–Cr–Sph (plot 4) plant communities in the southern peripheral and central parts of the mire. The mean and SD (indicated by vertical whiskers) values were estimated from measurements at three sample points in the Bet–Men–Sph and four sample points in Rh–Cr–Sph plant communities.
the Rh–Cr–Sph plant community \(-4.6 \pm 1.8\ \mu\text{mol m}^{-2} \text{s}^{-1}\) (6.0 \pm 0.2\ mg \text{ C g}^{-1} \text{ DW h}^{-1}\). Slightly higher values of GPP (expressed in mg \text{ C g}^{-1} \text{ DW h}^{-1}\) of Sphagnum riparium in the Bet–Men–Sph plant community can be explained by the individual eco-physiological properties of Sphagnum species and by the difference in ecological features of both experimental plots (WL, nutrient status, air and peat temperatures).

The maximal contribution to total RE for both plant communities comes from the sphagnum moss layer together with the sphagnum mat and peat. For the peripheral Bet–Men–Sph community RE of sphagnum and peat reached \(5.6 \pm 2.3\ \mu\text{mol m}^{-2} \text{s}^{-1}\) (total RE of the entire plant community \(-6.2 \pm 2.9\ \mu\text{mol m}^{-2} \text{s}^{-1}\), and it was higher than the RE of sphagnum and peat layer of the Rh–Cr–Sph community \(-4.6 \pm 1.1\ \mu\text{mol m}^{-2} \text{s}^{-1}\) (at total RE of the entire plant community \(-5.6 \pm 0.9\ \mu\text{mol m}^{-2} \text{s}^{-1}\), despite higher Sphagnum biomass in the Rh–Cr–Sph community and the difference in air and peat temperatures between the central and peripheral parts of the mire. In particular, on sunny summer days in July–August 2012 the air temperature in the central part of the mire was about 3–5°C higher than the air temperature in the peripheral part of the mire. The temperature difference of the peat horizons at 5 cm depth between the central and peripheral parts of the mire was only about 1.5–2.5°C. The contribution of herbaceous species and Oxycoccus palustris to the total RE of both plant communities was very small (figure 4).

The ET of the grass layer in the Rh–Cr–Sph community in the central part of the peat mire reached 0.06\pm0.03\ mm h\(^{-1}\) in July–August and was approximately twice as high as ET of the grass layer in the peripheral mire part (0.03 \pm 0.03\ mm h\(^{-1}\)). The contribution of the sphagnum moss layer with the sphagnum mat and peat to total ET was maximal in the central part of the mire (0.18 \pm 0.05\ mm h\(^{-1}\)). That is about ten times higher than ET of the sphagnum moss layer with mat/peat in the southern peripheral mire community (\(E_T = 0.01 \pm 0.01\ mm h^{-1}\)). The observed difference in ET between the two plant communities is mainly caused by the difference in temperature of sphagnum moss (8–12°C) that is reached in sunny summer days. WL ranged between 8 and 22 cm depth in different parts of the mire during the measuring period and it is responsible for some reduction of ET in summer months in comparison with spring fluxes.

Comparisons of our experimental data on NEE and ET with results of flux measurements in oligotrophic peat mires located in other regions of European Russia showed a relatively good agreement. In particular, the measured NEE and ET during the summer months in the central part of the mire are comparable with the results of eddy covariance flux measurements in the large peat mire ‘Staroselsky Moss’ (about 617 ha) situated at the southern boundary of the boreal forest zone in Tver region about 450 km to the north of our experimental site (Arneth et al 2002, Kurbatova et al 2002, 2009). According to results of the field measurements performed there from 1998 to 2000, the maximal daytime values of NEE in summer ranged on average between \(-3.0\) and \(-6.0\ \mu\text{mol m}^{-2} \text{s}^{-1}\), ET between 0.10 and 0.30 mm h\(^{-1}\), and RE between 2.0 and 6.0 \mu\text{mol m}^{-2} \text{s}^{-1}. Similar estimates of RE for both mires were observed despite higher peat and surface temperatures in the mire ‘Glavnoe’ in comparison with the peat mire ‘Staroselsky Moss’. The results obtained by Arneth et al (2002) show that the peat temperature at 5 cm depth in the mire ‘Staroselsky Moss’ in the summer months of 1998–2000 didn’t exceed 19°C whereas the peat temperature in the mire ‘Glavnoe’ at the same depth during the measuring periods in summer 2012 was always higher and ranged between 21 and 23°C. These NEE, RE and ET relationships can be explained by various factors, particularly by the differences in the degree of decomposition of the peat, WL, water content of the peat and sphagnum in these two mires.

The results describing the flux partitioning among different plant groups, sphagnum moss and peat in various types of mire and bog ecosystems are not well covered in modern experimental studies (Kim and Verma 1996, Schipperges and Rydin 1998, Heijmans et al 2004). We found no published experimental data describing flux partitioning in mire ecosystems situated in the central and northern regions of European Russia. Schipperges and Rydin (1998) provided laboratory estimations of GPP of several Sphagnum species (Sphagnum fuscum, Sphagnum papillosum, Sphagnum magellanicum, Sphagnum balticum and Sphagnum cuspidatum) that are similar to Sphagnum species growing in the mire ‘Glavnoe’. The GPP of these species changed from 0.3 to 1.1 mg \text{ C g}^{-1} \text{ DW h}^{-1}\ and these results agree well with the GPP estimates of Sphagnum species obtained in our experimental site.

4. Conclusion

The field measurements of NEE and ET were performed along a transect from the southern peripheral zone of the sphagnum mire to the center under sunny clear-sky and partly clear-sky conditions during the growing season of 2012 and in spring 2013. The results showed significant spatial and temporal variability of NEE exchange and ET that was mainly influenced by variations in incoming PAR, WL as well as in air and peat temperatures.

The maximal NEE was observed in the central part of the mire in June and reached 6.8 \pm 4.2 \mu\text{mol m}^{-2} \text{s}^{-1}\ whereas in the eutrophic southern peripheral part of the mire at the same time NEE at plots 1 and 2 was 0.6 \pm 0.9 \mu\text{mol m}^{-2} \text{s}^{-1}\ and 1.8 \pm 0.7 \mu\text{mol m}^{-2} \text{s}^{-1}\, respectively. A slight drying of leaves of grass species and decrease of photosynthesizing biomass of plants in July–August may be the main cause of an NEE reduction in both parts of the mire. The decrease of NEE in August can be also explained by very high air temperatures in the central part of the mire (up to 33–38°C). It resulted in a decrease of plant photosynthesis, an increase of plant and peat respiration and reduction of NEE. The peripheral part of the mire in August was a permanent source of CO\(_2\) for the atmosphere.

ET reached maximal values in the well-lighted central parts of the mire in May (0.34\pm0.20\ mm h\(^{-1}\)) mainly because of high air temperatures (up to 28–30°C) and overwatering.
of the upper peat horizon and sphagnum moss (WL ranged between 9 and 12 cm). Despite high air temperature in June–July (up to 28–30 °C in the central part of the mire) ET was slightly lower (ET = 0.17 ± 0.09 mm h⁻¹ at plot 4 in July) mainly due to decline of WL (14–17 cm). In August the air temperatures reached 33–38 °C and it can be considered to be the main reason for an ET increase up to 0.27 ± 0.09 mm h⁻¹ (at plot 4). ET at the southern peripheral part of the mire reached maximal values in July (ET = 0.03 ± 0.02 mm h⁻¹ at plot 1) and it was lower than ET values measured in the central part mainly due to low incoming solar radiation.

Our experiment to determine the contribution of the various plant groups and peat soil within different plant communities of the mire to total NEE and ET fluxes showed that the herbs have maximum contribution to GPP both in the central and peripheral parts of the mire. At both plots they were very similar: 3.9 ± 4.8 and 3.9 ± 1.3 mg C g⁻¹ DW h⁻¹ for the Bet–Men–Sph and Rh–Cr–Sph plant communities, respectively. The GPP of the sphagnum layer was relatively small than ET values measured in the central part mainly due to low incoming solar radiation.

Comparisons of observed NEE and ET for the sphagnum mire with measured fluxes in the other types of peat mires situated for example in boreal forest and sub-arctic regions showed a good agreement and indicated the significant role that peat mires can play in regional and global CO₂ and H₂O cycles. The main goal of further experimental studies will be to take into account the significant diversity of mires in the study area and to describe and compare the spatial and temporal variability of the CO₂ and H₂O fluxes in different mire types in the area. Moreover, it will be very important to quantify the sensitivity of the different plant species and Sphagnum in various types of mires to changes of incoming PAR, temperature regime and ground water level.

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