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Relationships between field-measured hydrometeorological variables and satellite-based land surface temperature in a hemiboreal raised bog

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ABSTRACT

Temperature regime is one of the main controlling factors of greenhouse gas (GHG) emissions from peat bogs. Remotely sensed land surface temperature (LST) has a potential to become an efficient instrument in environmental monitoring of carbon dioxide and methane emissions from peat bogs. This paper examines the relationships between field-measured hydrometeorological variables and MODIS LST data in a hemiboreal raised bog for a period from May to September (2008–2016). The Pearson product-moment correlation was used to reveal the relationship between the field-measured parameters and LST over years and months. A multiple linear regression was chosen to model relationships between the hydrometeorological variables and LST by month. It was found that the relationships between the studied parameters and LST were year- and month-dependent. The main factor of LST was air temperature, and the correlation between LST and air temperature was the strongest during the entire period of study. This study has shown that the hydrometeorological factors of LST can explain 67%–81 % of the variance in LST in a hemiboreal raised bog. The relationships between the hydrometeorological variables and LST may be implemented in more accurate GHG emissions estimation from bogs.

1. Introduction

In recent decades, carbon cycle has increasingly become a focus of studies investigating the climate system (Cox et al., 2000; Arora et al., 2013). Methane with a radiative forcing of 0.47 W m^{-2} plays a vital role in the feedback mechanism of climate change and leads to climate warming (Flato et al., 2013). The main global interannual variability of methane emissions is caused by natural wetlands fluctuations of CH_4 emissions. Of particular concern are emissions from northern peatlands, particularly from peat bogs, which possess a peat soil. Northern peatlands contain one-third of global soil carbon (Post et al., 1982; Dargie et al., 2017).

Methane emissions from peat bogs are controlled mainly by water table, temperature, vascular plant development and substrate mineralization (Hargreaves et al., 2001). Knowledge of temperature regime has great importance for understanding the complex biophysical processes in these ecosystems (Dorrepaal et al., 2009). Authors provide strong evidence of acceleration of the peat soil-related carbon respiration processes with an increase of temperature (Dorrepaal et al., 2009; Moore and Dalva, 1993; Sachs et al., 2010; Salm et al., 2012).

Simulations of future climate scenarios suggest an increasing tendency in warming and wetness for the northern ecosystems (Flato et al., 2013). What is not yet clear is the impact of these tendencies on CH_4 emission from the boreal peat bogs. Nowadays, with the aim to decrease uncertainty in this area, field measurements of greenhouse gases (GHGs) with chamber methods and eddy covariance towers are used in the wetland studies (Lee et al., 2017).

Presently, in addition to the field campaigns remote sensing techniques are widely used in studying wetland ecosystems respiration (Takeuchi et al., 2003; Akumu et al., 2010; Agarwal and Garg, 2009). There have been some studies related to the estimation of GHGs from wetlands at more detailed levels through the use of upscaling techniques (Takeuchi et al., 2003; Forbrich et al., 2011; Dinsmore et al., 2017). Also, remotely sensed land surface temperature (LST) data at various spatial resolutions and from different satellite sensors have been used as a proxy for temperature conditions to model ecosystems respirations. Akumu et al. (2010) and Agarwal and Garg (2009) assumed a positive linear relationship between LST and CH_4 emissions. Data of Landsat ETM and MODIS satellites were used in these studies for eastern Australia and the whole of India correspondingly. Schubert et al. (2010) described a positive exponential relationship between ecosystem respiration and diurnal MODIS LST product for a raised temperate ombrotrophic bog in southern Sweden.

It is now well established that LST can be adversely affected by certain conditions, such as atmospheric transmission and surface properties (Wan and Dozier, 1989). These conditions change over time

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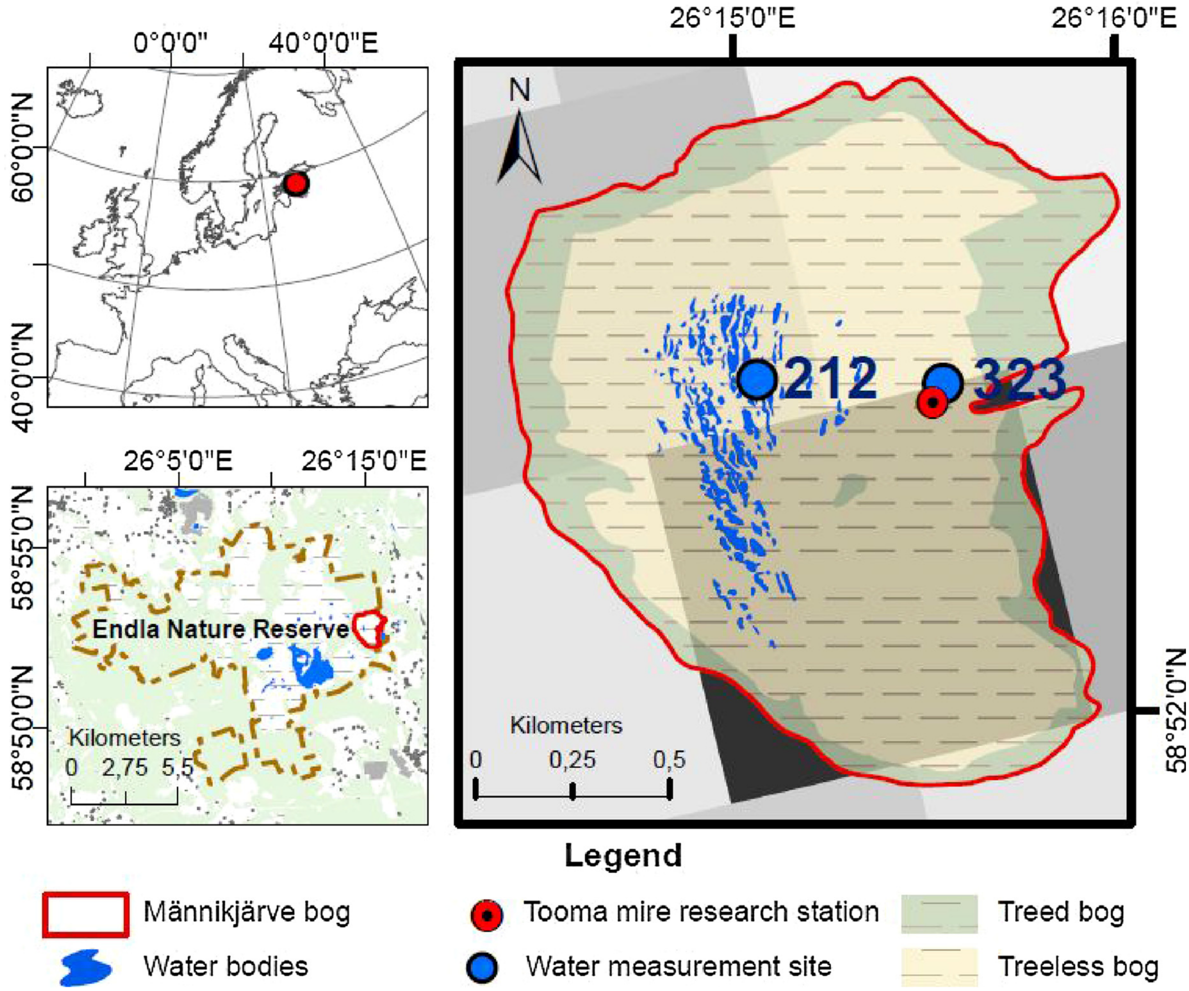

Fig. 1. Study area. The grey tetragons represent the MODIS MOD11A1 grid, whereas the shaded tetragon represents the MODIS pixel under consideration.

and they are season- and weather-related. In addition, water saturation, periodically standing water together with specific vegetation, give peat bogs unique emissivity properties (Tortini et al., 2017). Much uncertainty still exists about the temporal relationship between the environmental conditions and LST in bogs (Muro et al., 2018; Eisavi et al., 2016).

Thereby, in this paper we investigate relationships between ground-based hydrometeorological data and LST within three different temporal frameworks: 1)annual (2008–2016); 2) monthly (from May till September) over the 2008–2016 years; 3) study-period average. Data for nine years for the period from May till September were available, representing a wide range of environmental conditions of the growing season.

2. Methodology and data

2.1. Study Area

In our study, we used data from the Männikjärve Bog, which is located in central Estonia and belongs to the Endla Nature Reserve (Fig. 1). Männikjärve Bog is a convex ombrotrophic raised bog with a hummock, ridge-hollow and ridge-pool complex. Regional climate is temperate transitional between maritime and continental with average annual temperature 5.2 °C and annual precipitation of about 660 mm. Maximum peat depth is 7.5 m (Frenzel and Karofeld, 2000). Typical plants are dwarf *Pinus sylvestris, Ledum palustre, Vaccinium uliginosum, Calluna vulgaris, Empetrum nigrum*, and various *Sphagnum* species.

2.2. Hydrometeorological data

The Tooma mire research station provided us with the hydrometeorological data. In this study data from May to September for the period 2008–2016 were used. Air temperature (TAir) was measured at a height of 2 m every 3 h. Precipitation (Prec) was measured once a day (Table 1). Water vapour partial pressure (WVPP) was measured every 3 h. Soil temperature (TSoil) at depths of 5, 10, 15, 20 cm together with surface temperature (TSurf) were measured every 6 h.

We used water-level data from the WL 212 bog pool as well as in the soil at the location of WL 323. That was close to the woodland edge of the bog while WL 212 was located in the central part of the bog with sparse cover of dwarf pines. The difference between water-level fluctuations in peat and the pool is mainly caused by the difference in evaporation from the pool surface and from the capillaries (Paal et al., 2016). However, overall their water-level dynamics were consistent with each other (Fig. 2).

2.3. MODIS data

The cloud coverage is a major limitation in the use of optical TIR remotely sensed data. Unlike a weather station, TIR remote sensing techniques are unable to retrieve any information under a cloudy sky. Considering that as a result the information can be incomplete, we used MODIS LST data on a daily basis for a long period. The MODIS product MOD11A1 from the sixth collection at a 1 km spatial resolution provides daily long-term measurements of LST and emissivity.