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Satellite-based peatland mapping: Potential of the MODIS sensor

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Abstract

Peatlands play a major role in the global carbon cycle but are largely overlooked in current large-scale vegetation mapping efforts. In this study, we investigated the potential of the Moderate Resolution Imaging Spectroradiometer (MODIS) to capture the extent and distribution of peatlands in the St. Petersburg region of Russia by analyzing the relationships between peatland cover fractions derived from reference maps and ~1-km resolution MODIS Nadir BRDF-Adjusted Reflectance (NBAR) data from year 2002.

First, we characterized and mapped 50 peatlands from forest inventory and peat deposit inventory data. The peatlands represent three major nutritional types (oligotrophic, mesotrophic, eutrophic) and different sizes (0.6–7800 ha). In addition, parts of 6 peatlands were mined for peat and these were mapped separately. The reference maps provided information on peatland cover for 1105 MODIS pixels. We performed regression analysis on 50% of the pixels and reserved the remainder for model validation. Canonical correlation analysis on the MODIS reflectance bands and the peatland cover fractions produced a multi-spectral peatland cover index (PCI), which served as the predictor in a reduced major axis (RMA) regression model. The results suggest a high potential for mapping peatlands with MODIS. The RMA regression models explained much of the variance in the PCI ($r^2=0.74$ for mined and $r^2=0.81$ for unmined peatlands). Model validation showed high correlation between observed versus predicted peatland cover (mined: $r=0.87$; unmined: $r=0.92$). We used the models to derive peatland cover estimates for the St. Petersburg region and compared the results to current MODIS land cover maps.

Keywords: peatlands; mapping; satellite methods; regression analysis; carbon cycle; Russian Federation

1. Introduction

Peatlands constitute one of the most widespread wetland types in the world. The most significant regions in terms of absolute extent of peatlands are in Europe, including the former Soviet Union, and North America, in particular above 45° N (Charman, 2002). Despite their importance in the global carbon and hydrological cycle, and their significance as wildlife habitat, the global distribution and extent of peatlands remains uncertain (Maltby and Immirzi, 1993).

Peatlands are often referred to as organic wetlands, because of their characteristic layer of peat, which is plant detritus accumulated under anaerobic, water-logged conditions. Peat represents a major pool of organic carbon that amounts to about one-third to a half of the global soil carbon, which is almost the equivalent to the global atmospheric carbon pool (Charman, 2002). Total carbon stored in northern peatlands alone has been estimated to be about 455 Pg C (Gorham, 1991) with a

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current uptake rate in extant northern peatlands of 0.07 Pg C/yr (Clymo et al., 1998). At the same time, peatlands represent a major source of methane (CH_4) (Matthews and Fung, 1987) and dissolved organic carbon (DOC) (Freeman et al., 2004). Since atmospheric greenhouse gases are linked with the global climate system, global information on size and distribution of peatlands is of fundamental importance to climate change research. Currently, no clear consensus exists about the net effects of and feedbacks on future climate (IPCC, 2001).

For the last decades, global climate and biogeochemistry models largely depended on data derived from preexisting maps and atlases. Some of the most commonly used global data sets on wetland distribution were compiled by Olson and Watts (1982), Matthews and Fung (1987), and Aselmann and Crutzen (1989; later revised by Stillwell-Soller et al., 1995). These data sources rely on extensive historic in situ measurements and represent the best available information at the time. Nevertheless, their accuracy has not been rigorously assessed. As peatlands change over time in the process of their natural evolution and under the impacts of natural disturbances (e.g. fires), and human activities (e.g. peat mining, drainage and conversion to agricultural and forest land), the old maps likely become even less accurate.

Peatlands, particularly in the boreal region, tend to lack tree cover and represent distinct vegetation types (Botch and Masing, 1983; Gorham, 1991) that can be identified on satellite imagery. Since ground information on peatlands is often limited or even lacking in remote regions (Sheng et al., 2004), satellite remote sensing could provide a valuable tool for monitoring peatlands, especially in the northernmost latitudes. Several local and regional studies have mapped peatlands with high and medium spatial resolution sensors such as Landsat TM (30 m) and SPOT HRV (20 m) (Markon and Derksen, 1994; Poulin et al., 2002). However, mapping vast regions such as Northern Eurasia at fine spatial resolutions does not appear practical because of the lack of cloud-free imagery for many areas (DeFries et al., 1997; Krankina et al., 2004b). Further, there are considerable costs and logistical difficulties involved with handling such high data volumes, limiting the repeatability of such studies.

In comparison, the medium to coarse resolution sensor MODIS provides consistent and frequent observations of global land cover and land cover change processes at essentially no cost to the user (Townshend and Justice, 2002). Since the first global satellite based land cover map produced by DeFries and Townshend (1994) with data from the advanced high-resolution radiometer (AVHRR), substantial advancements have been made towards the development of comprehensive global vegetation and land cover data sets (Friedl et al., 2002; Justice and Townshend, 2002; Hansen et al., 2003). Nevertheless, peatlands are largely overlooked in large-scale land cover mapping efforts.

This study tested the capability of the MODIS sensor to map peatland cover proportions in a taiga landscape of the East-European plain. Results presented here may provide useful information for future mapping algorithms and therefore may promote the development of global land cover maps where peatlands are adequately represented.

2. Study area

The St. Petersburg region in Russia (Fig. 1) was selected as a test site, because of its location in one of the most significant peatland regions of the world. The abundance of peatlands in the St. Petersburg region is representative for northwestern Russia and is also close to the overall peatland proportion of the whole Russian Federation (8%) (Kobak et al., 1998). The study area occupies about 8 million hectare of flat terrain that rests on ancient sea sediments covered by a layer of moraine deposits. The natural vegetation belongs to the southern taiga type, and the climate is cool maritime. In terms of land cover, the study area is quite diverse. The region includes a major metropolitan area, St. Petersburg (5 million inhabitants) and a large agricultural region south and west from the city. Fifty-three percent of the region is covered with closed canopy forest, and repeated logging is a major disturbance factor, as is urban expansion and agricultural change (Krankina et al., 2004a).

The dominant peatland type in the region is the 'raised string bog' (Botch and Masing, 1983). Raised bogs have a dome-shaped surface built up of Sphagnum peat. In contrast to minerotrophic fens, raised bogs receive all their water and nutrients from the atmosphere (ombrotrophic). Therefore, they tend to be acid and low in nutrient availability (oligotrophic). According to Botch et al. (in preparation) oligotrophic bogs account for about 75% of the total peat volume in the St. Petersburg region, while transitional peat from mesotrophic peatlands and low-lying peat from fens or eutrophic peatlands comprise about 14% and 11%, respectively. In some areas peat is mined for use as fuel or soil conditioner. Mining removes the upper layers of peat, leaving bare peat surfaces that are often converted to agricultural or forested land. The consequences include rapid oxidation of the extracted peat into carbon dioxide and discharge of