Biogeosciences Discuss., 5, S2267–S2277, 2008
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Biogeosciences Discussions

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Interactive Comment

Interactive comment on "Meeting the challenge of mapping peatlands with remotely sensed data" *by* O. N. Krankina et al.

O. N. Krankina et al.

Received and published: 19 November 2008

On behalf of all co-authors I would like to thank reviewers for their thoughtful comments and constructive suggestions.

Response to G. Schaepman-Strub (Referee) gabriela.schaepman@wur.nl Received and published: 1 July 2008

GENERAL COMMENTS This paper gives an important insight into the status of peatland representation in re-mote sensing inferred land cover maps. It demonstrates the urgent need for improvements given the important role of peatlands in the global carbon cycle and the modeling thereof. This paper is analyzing existing maps and sources of their differences, without addressing what is needed (they might all be right for the purpose they address, but irrelevant to carbon cycling studies). I would suggest, also

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based on the well-chosen title, to start with a clear definition of peatlands (see suggestion below), explain why mapping of peatlands based on this definition is a challenge with optical remote sensing data (this might be clear to RS specialist in the current version, but not to the broad community addressed by the special issue), show the current status (as already included), point out what would be needed, and finally discuss ways forward. Given the fact that peatlands refer to a certain thickness of peat in the soil which is hidden to optical remote sensing techniques, I guess that this last part has to include a discussion on potential proxies (e.g. vegetation types, moisture conditions, seasonality, etc.) and combination of data sources. Connolly et al., 2007, might be a good inspiration for a user-driven combined approach. Connolly, J., Holden, N. M., and Ward, S. M.: Mapping peatlands in Ireland using a rule-based methodology and digital data, Soil Sci Soc Am J, 71, 492-499, 10.2136/sssaj2006.0033, 2007.

Response: The definition of peatlands was added to the introduction section as suggested. We also clarified the challenge of mapping peatlands based on that definition. The notion and examples of proxies were added. However we opted not to define specific ways forward in this paper beyond pointing out the need for improved mapping and certain opportunities offered by remotely sensed data and new methods of its utilization (integration of radar and optical data, continuous field approach to mapping land cover). The paper is focused on defining and quantifying the limitations and biases in available spatial data; further dialogue between the community of peatland ecologists, global modelers and remote sensing community is needed to develop specific requirements for globally consistent data on distribution of peatlands.

SPECIFIC COMMENTS Definition of peatlands in relation to what peatland maps should represent This paper needs a well-thought definition of what should be mapped and how this might deviate from the classical definition (Rydin, 2006) of peatlands. Response: Definition added as suggested (see next comment)

It remains unclear whether this paper addresses wetlands or peatlands, and if the map should also show peatlands which are covered by grasses, trees, etc., which can be

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very relevant for greenhouse gas emissions (for example in the Netherlands major peatland areas are under agricultural use, see also Schrier et al., this special issue). Thus, what kind of maps are needed for e.g. carbon modeling (carbon stocks and carbon fluxes), peatland ecology (e.g. wetlands versus peatlands, vegetation composition, drained peatlands), etc.? Maybe include reference of Beilman et al., 2008, on mapping of peat carbon stocks. David W. Beilman, D. H. V. J. S. B. S. F.: Peat carbon stocks in the southern Mackenzie river basin: Uncertainties revealed in a high-resolution case study, Global Change Biology, 14, 1221-1232, 2008. Rydin, H., and Jeglum, J.: The biology of peatlands, Oxford University Press Inc., New York, US, 343 pp., 2006: Peat is the remains of plant and animal constituents accumulating under more or less water-saturated conditions owing to incomplete decomposition. It is the result of anoxic conditions, low decomposability of the plant material, and other complex causes. Peatland is a term used to encompass peat-covered terrain, and usually a minimum depth of peat is required for a site to be classified as peatland. In Canada the limit is 40cm (National Wetlands Working Group 1997), but in many countries and in the peatland area statistics of the international Mire Conservation Group it is 30cm (Joosten and Clarke, 2002). Response: The definition of requirements for peatland maps needed to support C modeling are part of a broader and more basic problem that the paper addresses; the inadequacy of information on global distribution of peatlands. To clarify the distinction between wetlands and peatlands the following text was added to the third paragraph of introduction: Peat accumulates on land surface under more or less water-saturated conditions owing to anoxic environment, low decomposability of the plant material, and other causes (Rydin and Jeglum, 2006). In the boreal, sub-arctic and arctic zones, low temperature is a major factor that slows decomposition processes and virtually all vegetated wetlands have some peat accumulation. Peatland is commonly defined as peat-covered terrain with a minimum depth of peat set between 30 and 50 cm by different classifications. Multiple local and national peatland surveys have been conducted but globally consistent spatial data on distribution of peatlands is not available. This necessitates the use different proxi variables when

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maps of broad-scale distributions of peatlands are needed. Because of peatland association with water-saturated conditions, maps of wetlands are frequently used as a proxi. However in the boreal zone a significant portion of peatlands does not experience prolonged inundation and global assessments that are focused on hydrological characteristics (e.g., Matthews, 1989; Prigent et al., 2007) can be expected to represent peatlands inadequately in the boreal zone. Furthermore, the use of inundation as a proxi variable for mapping peatlands can exclude many drained peatlands that represent a large proportion of all peatlands in some regions. And then further: Because of its global availability the Global Distribution of Wetlands product (Matthews and Fung, 1987) is often used to define the occurrence of peatlands in global and circumpolar carbon cycling models (e.g., McGuire et al. 2007). Thus the robustness of carbon balance estimates depends substantially on the capacity of this or other global proxi datasets to represent accurately the distribution of peatlands. Vegetation cover is another proxi variable commonly used for mapping peatlands, especially in the boreal zone where peatland conversion to agricultural use is limited at the southern fringe and virtually non-existent in permafrost regions (Sheng et al., 2004; Beilman et al., 2008).

Significance of comparison between maps It remains difficult to judge the significance of the comparison between the maps as long as their purpose is not clearly set; the maps are based on different data sets (time span, spatial resolution), definitions and classes (e.g., wetlands versus bogs), methodologies, differences are expected. Response: While differences between the datasets can very well be expected, the extent of differences clearly shows that estimates of all global datasets are VERY low compared to the detailed map for our study region. The fact that a large proportion (74-99%) of peatlands was overlooked in global datasets is included in the abstract and in conclusions. Because nearly all wetlands in this region are peatlands, and most of the peatlands are bogs, mapping any one of those land cover classes would account for the majority of the other two. Thus the need for improved mapping appears obvious whether one is interested in wetlands or peatlands, in carbon cycling or hydrology; the currently available maps are used in all types of continental and global-scale studies.

To clarify the focus of the paper on the fundamental lack of pertinent spatial data the beginning of the last paragraph of the introduction was modified to read: This paper presents the results of a case study that compared data on peatland distribution from several widely used global and continental-scale databases with peatlands represented on detailed land cover map for the St. Petersburg region of Russia based on Landsat TM satellite imagery.

If understood correctly, the Russian reference map is a bog map, does this mean that the 25% meso-and eutrophic peatlands mentioned in the description of the area are omitted by the reference map? Response: The hand-drawn reference maps shows all types of wetlands. The text was corrected to reflect that.

It remains unclear, how much the material (inventory, Landsat scenes) of Oetter et al., 2001 and Pflugmacher et al., 2007 really differs. Obviously training datasets have a major influence on classification, even if in one case TM is used while in the other MODIS. Looks like good intercomparison results are biased by common basic material. Response: This is an important point to clarify because if common source material were used this could have been a problem. But, the ground datasets used for the two maps were separate and different; text was added to clarify that: The ground data set used to produce this map was separate from that involved in production and accuracy assessment of the Landsat-based land cover map (Oetter et al. 2001) which is used in this study as a basis for comparison.

TECHNICAL COMMENTS It took me too much time to identify the different maps/databases and their names (description versus names in Table 1). Suggestion: Describe LARSE land cover in same chapter as rest of remote sensing-based maps, introduce the database names as they appear in chapter where maps are explained, consistent with names in Table 1. Keep formatting style throughout the whole description (i.e. list style is abandoned for BALANS and LARSE peatland cover map). Response: Changes made as suggested

p. 2076, line 25: projecting their future change Response: Change made as suggested

p. 2077: Most people are used to get categorical maps from remote sensing – it would be helpful to include some more sentences or give an example for categorical versus continuous maps. Response: Good suggestion. Changes were made and now the text reads: An approach that could overcome this limitation of categorical maps is known as continuous field modelling; it estimates sub-pixel proportions of land cover types from remote sensing data. Continuous field maps hold some advantages as they provide improved spatial detail when compared to categorical maps that by definition discretize landscapes. Unlike classifications, continuous cover maps enable users to define their own thresholds for land-cover classes. Continuous field maps for forest cover have been developed for different regions in the world and from different sensor types, e.g. AVHRR (DeFries et al. 1997, Häme et al. 2001) and MODIS (Hansen et al. 2005). A continuous field map of peatland cover was created.

p. 2078: NBAR -explain abbreviation Response: We removed the term NBAR from this page and added a brief description and reference for NBAR to the paragraph that describes the MODIS peatland map more detailed: MODIS NBAR is a composite of multi-date, cloud-cleared and atmospherically corrected surface reflectance normalized to the mean solar zenith angle of a 16-day period (Schaaf et al. 2002).

p. 2079: High spatial resolution data classification is successful -it should be mentioned why this kind of data was not used in the current study (e.g. aim of global mapping?). Response: The successful mapping of peatlands with Landsat imagery is in fact used in this study as a reference for global datasets. The success at individual sites does not automatically translate into global scale maps – text was added to explain that: The success of peatland mapping at the scale of landscapes and small regions suggests that robust mapping at continental or global scale could be possible but the degree global relevance of site-specific results remains unknown.

p. 2080, line 11: What about disturbance by fire? Response: Fire is a relatively minor disturbance factor because of maritime climate in the study region and relative ease of fire control in an economically developed region with a fairly dense road network. Since fire is outside the scope of the paper we opted not to add this information. In case editors and reviewers feel it is critical it can be easily added.

p. 2088-9 and Fig. 3 and 4: It remains unclear if Fig. 3 only shows peatland classified pixels or all pixels of the area. If the wet classes correspond to the peatland pixels, this has to be mentioned in the text and figure title. Same applies to Fig. 4. For more details on spectral reflectance of vascular plants versus sphagnum you might look into Schaepman et al., special issue. Spectral signatures over the wet open areas might significantly be influenced by the seasonal changes of the solar angle (BRDF effects)! Response: To clarify this material we moved the description of ground data and now it is presented immediately prior to the Analysis of Spectral Signatures (sections 4.2 and 4.3). We also added text to clarify that 'wet' sub-classes correspond to peatlands and this determination was based on ground data. Thus, figures 3 and 4 show reflectance of ground polygons independently of their classification on the Landsat-based map. We clarified this by adding text on calculating polygon averages in the end of section 4.1 and adding text to the second sentence of 4.3: In terms of TC indices of brightness, greenness, and wetness, polygons labeled 'wet' based on ground information occupy the space between tree-dominated and herbaceous types on mineral soil.

Schaepman et al., special issue. http://www.biogeosciences-discuss.net/5/1293/2008/bgd-5-1293-2008.pdf…. the seasonal changes of the solar angle (BRDF effects)!

Response: We are thankful for the comment on the BRDF effects and we added the following sentence: Seasonal variations in the reflectance spectra are probably the result of phenological differences in the plant communities and changes in sun-angle. Further, we acknowledge that the temporal reflectance patterns could vary geographically.

p. 2091: Explain why radar might be an option.

In paragraph 4 (Introduction) we added a sentences that briefly describes why radar might be an option for peatland mapping: The advantage of radar sensors compared to multispectral sensors is that they can penetrate cloud cover and that they are sensitive to variable soil moisture conditions. In the following sentence we then describe the problems associated with radar-based peatland mapping: However, the lack of surface inundation during most of the growing season and variability of the water table over seasons and years is an obstacle for radar-based mapping of peatlands in the boreal zone. A more detailed discussion of radar remote sensing was beyond the scope of this paper.

Anonymous Referee #1 Received and published: 2 July 2008 The objective of this paper, as specified by the authors, is to provide guidance to improve the mapping of boreal peatlands from remote sensing observations. For that purpose, several databases on peatland distribution in the region of Saint Petersburg are compared and the spectral characteristics of different vegetation types are examined using Landsat TM measurements. 1) This paper provides a detailed and rather thorough review of the remote sensing of peatlands, insisting on the limitations of each technique. Different approaches are proposed, based on the vegetation or hydrology characteristics, and the authors insist on the vegetation-based classification. This introductory part is interesting and informative. Response: Thank you.

2) The study then concentrates on the area around Saint Petersburg and six databases of peatland distributions are carefully compared, showing very large differences that are attributed essentially to spatial resolution issues and definition problems. The differences being really important, which number to trust? Response: Mapping peatlands based on Landsat data was done successfully by Oetter et al. and others; unfortunately at the global and continental scales, no clear answer to the reviewer question can be substantiated by available data. This is a real problem that we aim to highlight while resolving it is unfortunately beyond the scope of the paper or the current knowledge.

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Are the same large differences expected in other places? Response: Another good question that cannot be fully answered with available data. There is at least one more study where large differences among examined datasets were reported (Frey and Smith 2007); it is mentioned in our conclusions. Furthermore, we have identified specific problems that are related to spatial resolution and categorical maps and legends those are presented as well. Thus similar problems could be expected in other places but this would be a speculation and we opted not to add that to the text.

All these datasets have been built from measurements taken at different time in the year. How important is the time factor in the classification methods? What is the sensitivity of the classification to the seasonal cycles? Response: It is not entirely true that all datasets were created with measurements taken at different time in the year. GLC.2000 and MODIS-IGBP.2001 use the satellite sensor record for the entire year in their classifications, BALANS and LARSE Landsat-based maps used data acquired over several years at somewhat different times within the growing season, GLWD likely has an even less defined time reference since it was compiled from several historic datasets. The only map with specific time reference is LARSE-MODIS since it was developed from MODIS data collected in early summer. Because peatland is a permanent land cover feature that does not fluctuate with changing seasons it is not clear if the time factor is important to the extent that the correlation between the proxi variable and the distribution of peatlands holds. In this regard less variable vegetation structure may have some advantages over hydrological attributes especially when there is a significant seasonal and interannual variability. We opted not to pursue this discussion theme because there seems to be insufficient data for a meaningful comparison of hydrology and vegetation structure as proxi variables in large-scale mapping.

3) The spectral signatures of peatlands are examined, using Landsat imagery. The results are not very convincing. Would these signatures also apply to other years, to other regions? What is the application of this analysis in terms of peatland classification? Response: The results show the limitations of spectral data as a basis

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for peatland classification within the matrix of other vegetation covers in a landscape, namely, the difficulty of mapping peatlands with increasing forest cover. However, the results are promising in that peatlands with predominantly herbaceous vegetation are spectrally different from herbaceous vegetation on mineral soils. Along with limitations we also point out the strengths of spectral data for land-cover classifications that include peatlands. First, peatlands occupy a fairly distinct spectral space (Fig. 3). We modified the text to clarify this point: “Successful automated mapping of peatlands with spectral imagery requires that peatlands are spectrally separable from other vegetation types. Several studies have demonstrated mapping of peatlands with multi-spectral sensor data of different spatial resolution (Poulin et al., 2002; Oetter et al., 2001; Bronge and Naslund-Landenmark, 2002; McGovern et al., 2000; Baker et al., 2006, Pflugmacher et al. 2007). Second, the analysis of spectral bands on figure 4 (i) shows that specific distinctions that can be made with Landsat data (namely separating peatlands from other lands dominated by herbaceous vegetation), (ii) indicates seasonal changes that can help with classification and (iii) demonstrates good agreement of our results with known spectral distinctions between sphagnum and vascular plants. The following text was added to explain the relevance of results: Seasonal variations in the reflectance spectra are probably the result of phenological differences in the plant communities and the changes in sun-angle. While it is not clear to what extent the same temporal patterns apply to other geographic regions and years, these results suggest that multi-temporal satellite data could improve the mapping of peatlands with spectral satellite data.

4) The conclusion takes the reader by surprise. I was expecting some developments about methods to improve the estimates of peatland distribution, following the analysis provided in section 4. This study fails to provide any guidance for better remote sensing of peatland. Several methods are alluded to (like combination of spectral sensor and radar data) but are not explored in this study. Response: Development of methods for improved global and continental mapping of peatlands is clearly a critical need. We do not feel that comprehensive guidance for better remote sensing of

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peatlands at global or continental scale can be provided based on data and knowledge gained from local and regional studies. Exploring the advantages and shortcomings of specific approaches and methods as they apply to broad-scale peatland mapping requires new research and interdisciplinary community effort from peatland ecologists, global biogeochemists, and remote sensing experts. To highlight the relevance of our results for improves broad-scale mapping of peatlands we added the following text to the conclusions section: (1) a sentence in the second conclusion explaining that the distinct spectral space that peatlands occupy “indicates the potential of spectral data to provide basis for improved mapping of peatlands with sparse or absent tree cover. (2) a sentence in the last conclusion that specifies continuous field modeling and explicit use of proxi variables as useful approaches: Continuous field mapping and explicit use of regionally appropriate proxi variables can help address some of the known limitations of available maps.(3) an additional an item in the conclusion section: Successful use of remotely sensed data for local and regional peatland mapping provides knowledge base from which methods for continental and global mapping can be developed. Meeting the challenge of global mapping of peatlands with remotely sensed data requires interdisciplinary research effort which includes peatland ecologists, global biogeochemists, and remote sensing experts. Usually justification of future research needs is not considered appropriate for a research paper thus we added the latter item with some hesitation.

As a conclusion, this study seems unfinished. Based on the analysis already provided in this paper, more efforts have to be done in order to develop new ideas and methods to improve the mapping of peatlands. Response: We feel that this paper helps to define the challenge and identify approaches to addressing it; we did examine specific weaknesses of available datasets and made suggestions for improved mapping of peatlands. But we do agree with this reviewer that more efforts are needed to fully develop ideas and methods and to test them at global and continental scale.

Interactive comment on Biogeosciences Discuss., 5, 2075, 2008.