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MAPPING OF WEST SIBERIAN WETLAND COMPLEXES USING LANDSAT IMAGERY: IMPLICATIONS FOR METHANE EMISSIONS

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Introduction. High latitude wetlands are important for understanding climate change risks because these environments sink carbon dioxide and emit methane. However, fine-scale heterogeneity of wetland landscapes poses a serious challenge when generating regional-scale estimates of greenhouse gas fluxes from point observations. Present land cover products fail to capture fine-scale spatial variability within The West Siberia Lowland (WSL) wetlands due to the lack of details necessary for reliable productivity and emissions estimates. Uncertainty in wetland inventory results in severe biases in CH_4 emission estimates, the scale of differences has been shown by Bohn et al. [2015]. In order to reduce uncertainties at the regional scale, we mapped wetlands and water bodies of the WSL on a scene-by-scene basis using a supervised classification of Landsat imagery.

Materials and Methods. Before mapping, about 90 suitable Landsat scenes of different years were collected; majority of them were Landsat 5 TM scenes from July 2007. The overall work flow involved data pre-processing, preparation of the training sample collections, image classification on a scene-by-scene basis, regrouping of the derived classes into 9 wetland complexes, the estimation of wetland ecosystem fractional coverage and accuracy assessment. Because WSL vegetation includes various ecosystem types, wetland environments were first separated from other landscapes to avoid misclassification. We used thresholds of the Green-Red Vegetation Index to separate majority of wetlands and forests. Surface water detection was performed using thresholds applied to Landsat's band 5 (1.55-1.75 μm). Masked Landsat images were filtered to remove random noises and then classified in Multispec v.3.3 (Purdue Research Foundation) using a supervised classification method.

As a primary source for training, we used the extensive dataset of botanical descriptions, photos, pH and electrical conductivity data from more than 40 test sites in WSL [Glagolev et al., 2011]. For further training dataset construction, we relied on the high-resolution images available from Google Earth (QuickBird, WorldView, GeoEye, IKONOS). We used following criteria for training samples, (i) they must be homogeneous; mixed land-cover and heterogeneous areas were avoided; and (ii) all of the samples must be at least 10 pixels in size with an average sample area of approximately 100-200 pixels. Classification mismatch between scenes was minimized by placing training samples in overlapping areas. The map accuracy assessment was based on 1082 validation polygons of 10×10 pixels that were randomly spread over the WSL. We used high-resolution images available in Google Earth as the ground truth information.

To develop wetland map, proper classification scheme is needed. Initially, this map was aimed at improvement of the regional CH_4 emission estimate. WSL wetlands are highly heterogeneous, however, within each wetland complex we can detect relatively homogeneous structural elements or "wetland ecosystems" with similar water table levels (WTL), geochemical conditions, vegetation covers and, thus, rates of CH_4 emissions [Sabrekov et al., 2013]. To ensure a reliable upscaling, we assigned 7 wetland ecosystems in our classification (Table).

However, wetland ecosystems generally have sizes from a few to hundreds of meters and cannot be directly distinguished using Landsat imagery with 30-meter resolutions. Therefore, we

Table. *Zonal distribution of wetland ecosystems and their emissions*

Wetland ecosystem	Forest-steppe and subtaiga		Taiga		Tundra	
	Area, Mha	Flux, $ktCH_4/yr$	Area, Mha	Flux, $ktCH_4/yr$	Area, Mha	Flux, $ktCH_4/yr$
Open water	1.41	35	5.94	88	4.36	33
Waterlogged hollows	0.27	54	5.22	1062	2.45	277
Oligotrophic hollows	0.09	16	13.25	1327	2.67	24
Ridges	0.30	14	8.69	40	0.95	0
Ryams	0.51	3	10.11	28	0.04	0
Fens	1.68	173	7.52	1403	0.93	25
Palsa hillocks	0	0	1.71	0	2.67	5
Total wetland area	4.27		52.44		14.07	
Total zonal area	66.96		157.97		49.78	
Paludification, %	6%		33%		28%	
Methane flux, ktCH4/yr	294		3948		364	

developed a second wetland typology that involves 9 mixed "wetland complexes" composing wetland ecosystems in different proportions. The criteria for assigning wetland complexes were: (i) separability on Landsat images, and (ii) abundance within WSL.

To merge typologies, we estimated relative areas of wetland ecosystems within each wetland complex of the final map. Depending on heterogeneity, 8 to 27 test sites of 0.1-1 km^2 size were selected for each heterogeneous wetland complex. High-resolution images of 1-3 meters resolution corresponding to these areas were classified in Multispec v.3.3 using visible channels. Their relative proportions were calculated and then averaged among the test sites.

Thus, we used multiscale approach relying in two typologies. First, typology of wetland complexes was used for mapping Landsat images; second, typology of wetland ecosystems was used for upscaling CH_4 fluxes.

Results and Discussion. Based on Landsat imagery, we developed new wetland map of the WSL. The total area of the WSL wetlands and water bodies was estimated to be 70.78 Mha; they account for 26 % of WSL area and 5-17 % of the global wetland area. WSL wetland area is larger than wetland areas in China, Hudson Bay Lowland and Alaska. The extent of West Siberia's wetlands exceeds the tropical wetland area of 43.9 Mha (see (Melton et al. [2013] and references there).

As summarized by Sheng et al. [2004], the majority of earlier Russian studies estimated the extent of the entire WS's mires to be considerably lower. These studies probably inherited the drawbacks of the original Russian Federation Geological Survey database, which was used as the basis for the existing WSL peatland inventories. They suffered from lack of field survey data in remote regions, a high generalization level and economically valuable peatlands with peat layers deeper than 50 centimeters were only considered.

Our peatland coverage is similar to the estimate of 68.5 Mha [Peregon et al., 2009] by State Hydrological Institute (SHI) map [Romanova et al., 1977]. However, a direct comparison between the peatland maps shows that the SHI map is missing fine-scale details. In addition, distribution of wetland ecosystem areas have changed significantly in comparison to SHI map [Peregon et al., 2009]; in particular, we obtained 105% increase in the spatial extent of CH_4 high-emitting ecosystems such as waterlogged, oligotrophic hollows and fens with corresponding effect on methane emission.

Concerning the wetland complex typology (excluding "Lakes and rivers" class), ridge-hollow complexes prevail in WSL, accounting for 26%

of the total wetland area, followed by pine bogs (19 %), ridge-hollow-lake complexes (18 %), palsa complexes (15 %), open fens (9 %), patterned fens (5 %), open bogs (4 %), and swamps (3 %). Various oligotrophic environments are dominant among wetland ecosystems, while different fens cover only 17 % of the area. Taiga zone contains 75 % of WSL's wetlands; their distribution was described in detail by Terentieva et al. [2016].

Concerning methane emission, taiga contributes 86 % to regional methane flux and tundra only 8 %, however ebullition in tundra lakes was not directly measured. Elevated environments as forested bogs and ridges emit the lowest rates of methane emission. They account for only 2 % of the regional total emissions occupying almost 40 % of the wetland area. Depressed environments as different types of hollows contribute 96 % to the methane regional flux covering 50 % of the wetland area in the region. Applying the new map resulted in total methane emissions of 4.62 $TgCH_4$/yr, which is 72 % higher than the estimate based on the same emission dataset and a map by Peregon et al. [2009]. The revision resulted from the changes in fractional coverages of methane emitting ecosystems due to the better spatial resolution of the new map.

Overall, we achieved the classification accuracy of 79 % that can be considered reasonable for such a large and remote area. We found that the accuracies for different land-cover categories varied from 62 to 99 %, with the lake and river, ryam, and RHC class areas mapped more accurately whereas open bogs and patterned fens being less accurate. Further improvement in the mapping quality will depend on the acquisition of ground truth data from the least discernible wetland landscapes and remote regions.

Our new Landsat-based map of WSL wetlands can be used as a benchmark dataset for validation of coarse-resolution global land cover products and for assessment of global model performance in high latitudes. Although classification scheme was directed towards improving CH_4 inventory, the resulting map can also be applied for upscaling of the other environmental functions.

DATASET source: http://www.biogeosciences.net/13/4615/2016/bg-13-4615-2016-supplement.zip

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