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Comparison and assessment of coarse resolution land cover maps for Northern Eurasia

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A B S T R A C T

Information on land cover at global and continental scales is critical for addressing a range of ecological, socioeconomic and policy questions. Global land cover maps have evolved rapidly in the last decade, but efforts to evaluate map uncertainties have been limited, especially in remote areas like Northern Eurasia. Northern Eurasia comprises a particularly diverse region covering a wide range of climate zones and ecosystems: from arctic deserts, tundra, boreal forest, and wetlands, to semi-arid steppes and the deserts of Central Asia. In this study, we assessed four of the most recent global land cover datasets: GLC-2000, GLOBCOVER, and the MODIS Collection 4 and Collection 5 Land Cover Product using cross-comparison analyses and Landsat-based reference maps distributed throughout the region. A consistent comparison of these maps was challenging because of disparities in class definitions, thematic detail, and spatial resolution. We found that the choice of sampling unit significantly influenced accuracy estimates, which indicates that comparisons of reported global map accuracies might be misleading. To minimize classification ambiguities, we devised a generalized legend based on dominant life form types (LFT) (tree, shrub, and herbaceous vegetation, barren land and water). LFT served as a necessary common denominator in the analyzed map legends, but significantly decreased the thematic detail. We found significant differences in the spatial representation of LFT's between global maps with high spatial agreement (above 0.8) concentrated in the forest belt of Northern Eurasia and low agreement (below 0.5) concentrated in the northern taiga-tundra zone, and the southern dry lands. Total pixel-level agreement between global maps and six test sites was moderate to fair (overall agreement: 0.67–0.74, Kappa: 0.41–0.52) and increased by 0.09–0.45 when only homogenous land cover types were analyzed. Low map accuracies at our tundra test site confirmed regional disagreements and difficulties of current global maps in accurately mapping shrub and herbaceous vegetation types at the biome borders of Northern Eurasia. In comparison, tree dominated vegetation classes in the forest belt of the region were accurately mapped, but were slightly overestimated (10%–20%), in all maps. Low agreement of global maps in the northern and southern vegetation transition zones of Northern Eurasia is likely to have important implications for global change research, as those areas are vulnerable to both climate and socio-economic changes.

1. Introduction

Information on land cover at global and continental scales is critical for addressing a range of important science questions such as the effects of vegetation on the carbon cycle, surface energy, and water balance, and socioeconomic causes and consequences of land-use and land-cover change (Bonan et al., 2002; Running et al., 2004; Zhang et al., 2009; Foley et al., 2005). The need for accurate land-cover information is particularly acute in Northern Eurasia, which encompasses high diversity of ecosystems that range from arctic deserts to the steppes and deserts of Central Asia, and climates that encompass polar and boreal climates of Siberia, monsoon climate in the

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east, and milder maritime climates in the Baltic Sea region. Because of this diversity, the area is a locus for climate change, and there is mounting evidence of significant recent changes in vegetation distribution, growing season duration, and patterns of snow cover and permafrost (e.g. Bulygina et al., 2010; Chapin et al., 2005; Randerson et al., 2006; Soja et al., 2007). The region also has unique and often poorly characterized land cover features, including vast expanses of larch (*Larix* spp.) forests, permafrost, wetlands, widespread disturbances (fire, harvest, pollution damage, insect damage), and drastic changes in land use following profound region-wide socioeconomic and institutional changes in the 1990s (e.g. Forbes et al., 2004; Groisman et al., 2009; Kuemmerle et al., 2008; Kuemmerle et al., 2009).

Since the mid 1990s substantial advances have been made toward the development of global vegetation and land cover datasets from moderate resolution satellite sensors. The first satellite-based global land cover maps were produced with data from the advanced high-resolution radiometer (AVHRR) (DeFries & Townshend, 1994; Hansen et al., 2000; Loveland et al., 2000). In 1998 and 1999, AVHRR was followed by VEGETATION-1 onboard the fourth Satellite Pour l'Observation de la Terre (SPOT) and the Moderate Resolution Imaging Spectroradiometer (MODIS), which allowed the concurrent development of two additional global land cover products: GLC-2000 (Bartholome & Belward, 2005) and the MODIS Global Land Cover Product (Friedl et al., 2002). More recently, two new global land cover datasets have been released: GLOBCOVER derived from Medium Resolution Imaging Spectrometer (MERIS) data (Arino et al., 2008) and the MODIS C5 Land Cover Product (Friedl et al., 2010). The most important change in the evolution of these datasets is the increase in spatial resolution from ~1 km (MODIS Collection 4 — hereafter MODIS C4 — and GLC-2000) to ~500 m (MODIS Collection 5, hereafter MODIS C5) and ~300 m (GLOBCOVER). Because many land cover features occur at a spatial resolution finer than 1 km (Gerlach et al., 2005; Krankina et al., 2008; Skinner & Luckman, 2004), the higher spatial resolution should improve the representation and accuracy of the GLOBCOVER and MODIS C5.

The availability of multiple, similarly structured land cover data sets provides the user community with choices, but for most users it is not clear which map suits their particular application best (Herold et al., 2008; Jung et al., 2006). Ultimately, the selection is often based on map legends rather than accuracy, in part because it is difficult to ascertain which map is the most accurate. Global accuracy estimates reported by map developers are very similar, but because of methodological differences used to perform the accuracy assessments, these estimates cannot be directly compared, e.g. GLC-2000: 68.6% (Mayaux et al., 2006), GLOBCOVER: 73.1% (Bicheron et al., 2008), MODIS Collection 3: 71.6% (MODIS land cover team, 2003), and MODIS Collection 5: 74.8% (Friedl et al., 2010).

While users often rely on overall measures of map accuracy to evaluate the quality of maps, map errors are rarely equally distributed (Strahler et al., 2006). Two maps can have the same overall accuracy, but a different spatial distribution of error. Studies that compared global land cover maps have found significant regional differences in spatial agreement (Fritz & See, 2008; Giri et al., 2005; Herold et al., 2008). Agreement tends to be lowest in regions with complex, heterogeneous land cover and for spectrally similar land cover classes (e.g. mixed versus pure broadleaf and conifer forests). Thus, the choice of map depends on how it will be used in a particular region of the map, which also needs to be considered in interpreting results of spatial modeling.

Differences among land cover maps have important implications for applications using these products, for example biogeochemical (e.g. Potter et al., 2008) or habitat models (e.g. Kuemmerle et al., 2011). A simple analysis that extrapolated results of biogeochemical modeling for the Arctic region of Northern Eurasia (North of 60°) showed that a very different picture of the regional carbon (C) balance emerged when different vegetation maps were used as model inputs: The estimate of C stock in live vegetation based on the GLC-2000 map (24 Pg C) was 40% higher than the estimate based on the MODIS plant functional type map (17 Pg C). Although the estimates of the total change in live vegetation C stocks were very similar for both maps (0.2 Pg yr^{-1} C sink), the attribution of the projected C sink was quite different depending on the map used: based on GLC-2000 map most of the C accumulation occurred in tree-dominated ecosystems while simulations using the MODIS map attributed most of the C sink to shrub vegetation (Krankina et al., 2011). The significant role of land cover map selection on forest biomass estimates in Russian forests was also reported by Houghton et al. (2007).

Despite the importance of Northern Eurasia for global change research, global maps have not been rigorously assessed in this region. For GLC-2000, Bartalev et al. (2003) compared estimates of percent forest cover with official forest cover statistics for administrative regions of the Russian Federation. The authors reported an R^2 of 0.93, indicating that forest cover was reliably mapped at the level of administrative units. The size of administrative divisions in Russia, however, varies considerably, i.e. from about 8×10^3 km^2 (Adygea) to 3×10^6 km^2 (Yakutia). Frey and Smith (2007) compared field observations in Western Siberia with two land cover and two wetland databases. Agreement between the field data and the two analyzed land cover data sets, the AVHRR Global Land Cover Characterization Database and the MODIS C3 Land Cover Product, was 22% and 11%, respectively. Other comparison studies have focused only on wetlands (Krankina et al., 2008; Pflugmacher et al., 2007).

Cross comparisons between global land cover maps help identify areas of potential high map uncertainty (Herold et al., 2008; See & Fritz, 2006), but independent validation studies are needed to reveal the sources of disagreement and provide local and regional scale estimates of classification accuracy. There are several challenges associated with this task:

- The collection of reference data is costly for large areas, particularly for remote regions such as Northern Eurasia. Consequently, it is crucial to design and implement validation methods that are not tailored to a single map product, i.e. a single classification system and spatial resolution, but that can accommodate a range of current and potentially future land cover maps (Olofsson et al., submitted for publication).
- Reference data is often collected at high spatial resolution and needs to be aggregated to the resolution of the coarse-scale map. The process of aggregation, however, can introduce biases towards dominant land cover types ("low resolution bias", Boschetti et al., 2004; Latifovic & Olthof, 2004; Moody & Woodcock, 1994).
- Maps differ with respect to spatial resolution, class definitions and thematic detail. This affects estimates of overall map accuracy (Latifovic & Olthof, 2004), and therefore makes cross-comparison of accuracy estimates difficult.

The objective of this study was to evaluate accuracy measures and procedures for validating global land cover datasets for Northern Eurasia using maps created from higher resolution satellite data (Landsat). This study is part of a broader effort to validate and improve land cover and land-cover change products for Northern Eurasia using a network of local test sites distributed throughout the region (http://www.fsl.orst.edu/nelda).

2. Methods

We compared four global land cover datasets with higher resolution (30-m) land cover maps developed from Landsat images at test sites distributed throughout the region of Northern Eurasia. Ideally, it is desirable to choose reference locations by random probability sampling (Strahler et al., 2006). However, the availability of reference data in this region represents a major constraint for validation studies. We therefore selected test sites across a range of climatic and