Accuracies of Global Land Cover Maps Checked against Fluxnet Sites

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Global land cover data products are key sources of information in understanding the complex interactions between human activities and global change. They play a critical role in improving performances of ecosystem, hydrological and atmospheric models. Three freely available global land cover products developed in the United States are popularly used by the scientific community. These include two global maps developed separately by the United States Geological Survey (USGS) and the University of Maryland (UMD) with NOAA Advanced Very High Resolution Radiometer (AVHRR) data, and one developed by Boston University with the EOS Moderate Resolution Imaging Spectroradiometer (MODIS) data. They are compared with known land cover types at 250 available Fluxnet sites around the world. The overall accuracies are 37%, 36% and 42%, respectively for the USGS, UMD and Boston global land cover maps. Some future global land cover mapping strategies are suggested.

Key words global land cover map

Four global land cover maps derived from remotely sensed data are freely available for global change studies. Three of them are developed in the United States by (1) United States Geological Survey (USGS)[1]; (2) University of Maryland (UMD)[2]; and (3) Boston University[3]. The fourth one is (4) Global Land Cover 2000 (GLC2000) developed in Europe[4]. Spatial units of these digital products are all 1 km. Data sources used for the USGS and UMD global land cover maps are derived from monthly normalized difference vegetation index (NDVI) composites in 1992—1993 with NOAA AVHRR data. The GLC2000 uses monthly NDVI data derived from 1999—2000 SPOT Vegetation data. The Boston global land cover maps are derived from MODIS data acquired in 2000—2001. The classification schemes used by the three US global land cover maps are in accordance with the IGBP classification system with 17 categories of cover types while the GLC2000 has a 22 category classification scheme adopted from the Food and Agricultural Organization. All land cover data products are generated by computer classification algorithms. The USGS map was based on clustering and refinement while the UMD and Boston map products were produced with different classification tree algorithms. The GLC2000 was produced by a large number of people working separately on 19 different regions of the world using various types of algorithms. The accuracies of these land cover maps are not provided.

Several studies report a great deal of error in these products[5,6]. In a mapping effort over approximately 100 000 km^2 of Miombo ecosystem in Mozambique with MODIS data, it was found that the Boston global land cover map is almost entirely wrong when verified using more than 400 visited field sites and Landsat Thematic Mapper imagery[5]. 2161 field visit sites were compared with several land cover maps including the USGS and Boston products over an area of approximately 1 million km^2 in Siberia, Russia[6]. The overall accuracies were found to be only 22% and 11% for the USGS and Boston land cover maps, respectively. A consistency check among the above mentioned four global land cover maps found that the only major regions classified similarly in all four datasets were the snow/ice regions over Greenland, the barren/sparsely vegetated regions over Africa and the tropical evergreen broadleaf forests of Brazil, amounting to a total of 26% of the globe[7]. Among seven selected sites from Africa, Asia, Australia, Europe, North America, Russia and South America, only in South America the four maps agree for over 80% and the remaining six sites are all below 20%.

There are over 500 Fluxnet sites (http://www.fluxnet.ornl.gov/fluxnet/siteplan.cfm) today. Only 250 sites reported their land cover types. They are used to assess the accuracies of the global land cover maps for three reasons. First, flux measurement sites are required to be homogeneous for approximately greater than 4 km^2 making each Fluxnet site an ideally pure sample. Second, their locations are precisely known. Third, the reported classes are in IGBP categories that make them directly comparable to the three global land cover maps developed in the US. For the last reason, the GLC2000 dataset was not chosen in the assessment.

The 250 Fluxnet sites are shown in Figure 1 with the USGS global land cover map in the background. Clearly the distribution is uneven with a majority located in Western Europe and North America. Because the global land cover maps are prepared in the geographical coordinate system, it is relatively easy to project the latitude and longitude of each Fluxnet site on these maps. An error matrix is summarized for each land cover map from which accuracies for individual classes and the overall accuracy can be calculated (Tables 1-3). Only 11 categories are found from the Fluxnet sites and they are evergreen needleleaf forest, evergreen broadleaf forest, deciduous broadleaf forest, mixed forest, closed shrublands, open shrublands, woody savannas, savannas, grasslands, persistent wetlands, and croplands. At the bottom of each table the total number of samples found in the Fluxnet sites is listed for each land cover type. While evergreen needleleaf forest, deciduous broadleaf forest, grassland and croplands each has 30 sample sites or more, less than 10 sample sites are available for closed shrub, woody savannas and savannas. The incomplete categories, insufficient number of samples and uneven spatial distribution of the Fluxnet sites make it impossible to fully assess the quality of those global land cover maps. However, they represent a consistent source of ground truths at the global scale for us to gain some insight on the quality of those global maps.

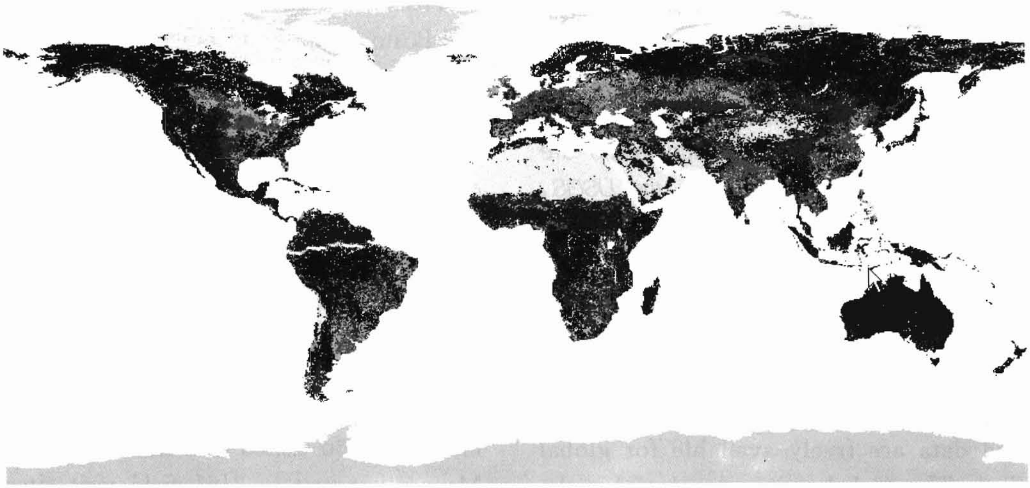

Figure 1 Fluxnet sites (red) overlaid on USGS global land cover map

Table 1 shows the agreement and disagreement between the Fluxnet sites and the USGS global land cover map. The diagonal elements are those that agree while the off-diagonal elements report the number of Fluxnet sites with a class type indexed in the top of the table being misclassified to a category on the left of the table. Dividing the total of correctly classified sites by the total number of sites gives the overall accuracy. The ratio is only 0.37 meaning a 37% accuracy. Among the individual classes, only the evergreen broadleaf forest, mixed forest and croplands are more than 50% accurate. A large number of evergreen needleleaf forest sites are classified into mixed forest, the same happened with grassland and deciduous broadleaf forest being misclassified into crop lands.

Table 1 Error matrix between USGS land cover map and Fluxnet land cover types. The correct class labels for the Fluxnet sites are in the top row while their classified labels are found in the leftmost column.

	USGS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	Evergreen Needleleaf Forest	34	0		0	1	1	2	2	0	4	3	1						
2	Evergreen Broadleaf Forest	0	9		0	0	0	0	1	0	0	0	1						
3	Deciduous Needleleaf Forest																		
4	Deciduous Broadleaf Forest	3	1		7	1	0	1	0	0	3	0	0						
5	Mixed Forests	16	1		7	9	0	3	0	0	4	0	0						
6	Closed Shrublands	0	1		2	0	0	0	0	0	0	0	1						
7	Open Shrublands	1	1		1	0	0	2	0	0	0	1	0						
8	Woody Savannas	1	0		1	0	0	0	2	1	4	0	0						
9	Savannas	0	0		0	2	0	0	1	0	0	0	0						
10	Grasslands	0	0		0	0	0	1	2	1	7	0	1						
11	Persistent Wetlands	0	0		0	0	0	0	0	0	0	0	0						
12	Croplands	5	2		10	2	0	0	1	1	15	3	23						
13	Urban and Built-Up	0	0		1	0	0	0	0	0	0	0	1						
14	Cropland/Other Vegetation Mosaic	9	2		2	1	2	1	0	1	5	2	2						
15	Snow and Ice																		
16	Barren or Sparsely Vegetated	0	0	0	0	0	0	0	0	0	0	2	0						
17	Water	0	1	0	1	0	1	2	0	0	3	0	0						
	Total	69	18		32	16	4	12	9	4	45	11	30						**250**
	Class accuracy	0.49	0.5		0.22	0.56	0	0.17	0.22	0	0.16	0	0.77						
	Overall accuracy																		**0.37**

Table 2 shows the agreement between the Fluxnet sites and the UMD land cover map. The UMD classification system does not include wetland and croplands with other vegetation mosaics categories. The overall accuracy is only 36%. Only the closed shrublands and croplands exceed 50% accuracy. Evergreen needleleaf forest has been misclassified into mixed forest and closed shrublands, grasslands has been misclassified into open shrublands and crop lands, and deciduous broadleaf forest has been misclassified into croplands, mixed forest and shrublands.

Table 2 Error matrix between UMD land cover map and Fluxnet land cover types. The correct class labels for the Fluxnet sites are in the top row while their classified labels are found in the leftmost column.

	UMD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15*	
1	Evergreen Needleleaf Forest	32	1		0	3	0	1	0	0	3	0				**4**	
2	Evergreen Broadleaf Forest	0	8		0	0	0	0	0	0	0	1					
3	Deciduous Needleleaf Forest																
4	Deciduous Broadleaf Forest	4	0		7	3	0	0	0	0	2	0					
5	Mixed Forests	8	0		5	3	1	2	0	0	2	0					
6	Closed Shrublands	14	2		4	5	2	2	4	1	4	0				**1**	
7	Open Shrublands	5	2		4	1	0	1	3	1	10	3				**1**	
8	Woody Savannas	2	0		2	0	0	1	1	0	0	0					
9	Savannas	0	1		0	0	0	2	1	1	0	0				**2**	
10	Grasslands	0	1		2	0	1	2	0	0	10	0				**1**	
11	Croplands	2	1		7	1	0	0	0	1	9	26				**1**	
12	Urban and Built-Up																
13	Snow and Ice	0	0		1	0	0	0	0	0	0	0					
14	Barren or Sparsely Vegetated	2	2		0	0	0	1	0	0	5	0					
	Total	69	18		32	16	4	12	9	4	45	30				11	**250**
	Class accuracy	0.46	0.44		0.22	0.19	0.5	0.08	0.11	0.25	0.22	0.87				0	
	Overall accuracy																**0.36**

* Permanent Wetlands not included in this classification.

In Table 3, the overall accuracy for the Boston global land cover map is 42%. Five cover types have greater than 50% accuracies. They include evergreen needleleaf forest, evergreen broadleaf forest, mixed forest, savannas and croplands. The error patterns are similar to the two maps discussed earlier. The Boston land cover map contains much more spatial details than the USGS and UMD maps due to the substantially improved image resolution of MODIS data in comparison to the AVHRR data.

Table 3 Error matrix between MODIS land cover map and Fluxnet land cover types. The correct class labels for the Fluxnet sites are in the top row while their classified labels are found in the leftmost column.

	MODIS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	Evergreen Needleleaf Forest	39	0		1	0	1	2	0	0	2	4	0						
2	Evergreen Broadleaf Forest	2	11		0	0	0	0	0	0	0	0	1						
3	Deciduous Needleleaf Forest																		
4	Deciduous Broadleaf Forest	1	0		3	2	0	0	1	0	0	0	0						
5	Mixed Forests	17	1		12	12	2	3	0	0	8	1	2						
6	Closed Shrublands	0	0		0	0	1	0	0	0	0	0	1						
7	Open Shrublands	2	0		2	1	0	3	1	1	2	2	1						
8	Woody Savannas	1	0		3	0	0	1	3	0	2	1	0						
9	Savannas	1	2		0	0	0	0	3	3	3	0	0						
10	Grasslands	0	1		0	0	0	1	1	0	9	2	1						
11	Persistent Wetlands	0	0		0	1	0	0	0	0	0	0	0						
12	Croplands	2	2		6	0	0	0	0	0	11	1	21						
13	Urban and Built-Up	0	0		1	0	0	0	0	0	2	0	2						
14	Cropland/Other Vegetation Mosaic	3	0		3	0	0	1	0	0	3	0	1						
15	Snow and Ice																		
16	Barren or Sparsely Vegetated	0	1		0	0	0	1	0	0	0	0	0						
17	Water	1	0		1	0	0	0	0	0	3	0	0						
	Total	69	18		32	16	4	12	9	4	45	11	30						250
	Class accuracy	0.57	0.61		0.09	0.75	0.25	0.25	0.33	0.75	0.2	0	0.7						
	Overall accuracy																		0.42

It is not easy to correctly classify a large number of land cover categories even with high spatial or spectral resolution data[8,9]. This is particularly true at the global scale because land cover types vary to the greatest extent. Among the 17 categories of IGBP land cover types, our knowledge on how to properly classify them varies with classes. The relatively high individual class accuracies imply better accessibility to reference data on these classes. More research attention given to forest and crop lands led to better individual class accuracies in those classes. Neither the USGS map nor the Boston map has correctly picked up the 11 wetland sites (the UMD map does not have this class). The classification accuracies also vary with location. Out of the 102 Fluxnet sites in North America, the classification accuracies increase to 49% and 48%, for the USGS and Boston maps, respectively. These are considerably higher than the global overall accuracies. This is also generally true to land cover mapping at other spatial scales[10].

Global land cover mapping is a challenging task to remote sensing scientists from almost every aspect of remote sensing including data collection, geometric and atmospheric correction, mosaicing, feature extraction, classification, and accuracy assessment. Although a tremendous amount of research has been devoted to land cover mapping with remotely sensed data, the present capability in producing accurate land cover maps over large areas with computers is far from satisfactory. A great number of image classification algorithms have been proposed and there is no general agreement on the best performers. Not only new algorithms need to be continuously developed[11,12], but more efforts should also be made to integrate the strengths of various classifiers[13]. The distributed partnership strategy developed for the GLC mapping is interesting but it is important to maintain consistency and standard. More *in situ* or high resolution satellite data are critical sources of training information for global land cover mapping. Presently, most land cover products are produced from data acquired with a single type of sensor, more efforts in the future should be devoted to make combined use of data not only from different times but also from different sensors. Finally, since some land cover categories are consistently poorly classified by general-purpose classifiers, alternative approaches should be developed to extract individual land cover types. In fact, detection and extraction of individual land cover types should be emphasized in future land cover mapping efforts.

Acknowledgements

The author is grateful to research support from the US National Science Foundation grant (NSF DEB 04-21530), and the National Natural Science Foundation of China (30590370).

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(19 November 2008; accepted 1 December 2008)