International Journal of Remote Sensing
Vol. 31, No. 2, 20 January 2010, 391–401

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Evaluation of four remote sensing based land cover products over China

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(*Received 17 November 2006; in final form 6 June 2008*)

Precise global/regional land cover mapping is of fundamental importance in studies of land surface processes and modelling. Quantitative assessments of the map quality and classification accuracy for existing land cover maps will help to improve accuracy in future land cover mapping. We compare and evaluate four land cover datasets over China. The datasets include the Version 2 global land cover dataset of IGBP, MODIS land cover map 2001, a global land cover map produced by the University of Maryland, and the land cover map produced by the global land cover for the year 2000 (GLC 2000) project coordinated by the Global Vegetation Monitoring Unit of the European Commission Joint Research Centre. The four maps used different classification systems, which made the comparison difficult. So we first aggregated these maps by reclassifying them using a unified legend system. A large-scale, i.e. 1:100 000 land cover map of China was used as the reference data to validate the four maps. The results show that the GLC2000 land cover map represents the highest accuracy. However, it has obvious local labelling errors and a zero labelling accuracy for the wetland type. The MODIS land cover map ranks second for type area consistency and third for sub-fraction overall accuracy compared with reference data, which may be affected by the local labelling error. The IGBP land cover map has good labelling accuracy, although it has a local labelling error and third consistency for type area. The labelling accuracy and type area consistency for the reference data of UMd land cover map is low. We conclude that the accuracies of all the datasets cannot meet the requirements of land surface modelling. For the reference data, i.e. the 1:100 000 land cover map, the classification system needs to be transferred to a well recognized one that has been used commonly in land surface modelling. In addition, we propose an information fusion strategy to produce a more accurate land cover map of China whose classification system should be compatible with the well-accepted classification system used in land surface modelling.

1. Introduction

Land cover plays a significant role in Earth system science, which reflects the influence of human activities and environmental changes (IGBP 1990, Sellers *et al*. 1997, Aspinall and Justice 2004). The land cover change impacts the function and structure of terrestrial surface process such as energy exchange, water cycle, biogeochemical cycle and vegetation productivity. Hederson *et al*. 1983, Crutzen and Andreae 1990, Keller *et al*. 1991, Turner *et al*. 1995). Reliable and up-to-date land cover data are very important for land, ecological and hydrological modelling (Sellers *et al*. 1997), carbon

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International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online © 2010 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160902893451

and water cycle study (Sellers *et al*. 1997) as well as global climatic change study (Shi *et al*. 2000, IPCC 2001).

Many land use/cover maps at global, continental and regional scales have been produced in recent years using remote sensing. Among them, four land cover maps are very popular: Version 2 International Geosphere Biosphere Programme (IGBP) global land cover dataset (IGBP-DISCover) (Loveland *et al*. 2000), the UMd (the University of Maryland) land cover map (Hansen *et al*. 2000), the map from the European Commission Joint Research Centre (Global land cover for the year 2000, GLC2000; Bartholome and Belward 2005), and the MODIS (the moderate resolution imaging spectroradiometer) global land cover map (Friedl *et al*. 2002).

These four global land cover maps are all derived from remote sensing data and created for the same fundamental purpose of providing improved land cover information for scientific studies and environmental monitoring, but they are different in mapping methods, data sources and classification systems. Their accuracies may also be quite different and need to be evaluated. This is a prerequisite for using them in land surface modelling and other applications.

In China, the national project of high resolution land use mapping is implemented every five years based on remote sensing technology. The Chinese land cover map uses a classification system that can be used to monitor land cover change but is not favourable for identifying the physiological properties of vegetation. Therefore, it cannot generally be used in land modelling.

The objective of this paper is to evaluate the application of the four popular land cover maps over China land mass. To do so, we first clarified their similarities and differences, and then evaluated their accuracies by using a large-scale (1:100 000) land cover map of China. The possibility of developing a new land cover map whose classification is compatible with well-accepted legend system but whose accuracy is more reliable also motivates this study.

2. Data and method

2.1 *Land cover maps*

Four land cover maps were evaluated over China's land territory. They include:

- the IGBP global land cover classification data produced by the United States Geological Survey (USGS) (Loveland *et al*. 2000);
- the UMd global land cover classification data produced by the University of Maryland (Hansen *et al*. 2000);
- GLC2000 China (GLC2000-China) regional classification data produced by the Institute of Remote Sensing Applications, Chinese Academy of Sciences and the USGS for the Global Land Cover 2000 initiative (Xu *et al*. 2005); and
- the MODIS global land cover classification map produced by Boston University in 2000 (Friedl *et al*. 2002).

The characteristics of the four land cover maps are summarized in table 1.

2.2 *Reference data*

The large-scale (1:100 000) land use map of China in 2000, which was produced by Chinese Academy of Science to meet large-scale resource survey and land use mapping, was used as truth to validate the four land cover maps over China. This map

Table 1. Similarities and differences in product among IGBP-DISCover, UMd, GLC2000 and MODIS land cover products.

	IGBP DISCover	UMd	GLC2000	MODIS
Sensor	AVHRR	AVHRR	SPOT-4 VGT	MODIS
Time of data collection	April 1992–March 1993	April 1992–March 1993	January 2000–December 2000	January 2001–January 2002
Classification technique	Unsupervised clustering	Supervised classification tree	Unsupervised algorithm	Decision tree classifier with boosting
Processing sequence	Continent-by continent	Global	Region-by-region	Global
Input data	12 monthly NDVI composites	41 metrics derived from NDVI and bands 1–5	36 10-day NDVI and geophysical datasets composites	16-day Nadir BRDF-Adjusted Reflectances; seven spectral bands; 16-day EVI
Classification scheme	IGBP (17 classes)	Simplified IGBP (14 classes)	LCCS (22 classes)	IGBP (17 clases), UMd (14 classes)
Intended application	Global change	Global change	Multi-purpose	Multi-purpose
Validation	September 1998	Evaluated using other digital datasets	Statistical data	Quantitative studies of output and training data and sample-based statistical studies

inherited the land cover classification system drafted by the 'Eighth Five-Year Plan' project, Resource and Environment Remote Sensing Survey and Change Research in China (Wu and Guo 1994, Liu 1996). The database is derived from Landsat MSS, TM, and ETM images, and mainly by manual interpretation based on the experiences of experts. The boundaries of the objects were delineated based on the interpreters' understanding of the spectral reflectance, texture, and terrain and other information of objects. Then the attributes (labels) of the polygons were labelled to produce the digital map. Finally the vector digital maps were edited and compiled (Liu *et al.* 2005). The database has been validated by intensive field surveys including an accumulated survey length of 75 271 km across China. The overall accuracy of the land use map was 95% for 25 land use classes, which is the highest accuracy among the national-scale land use data products over China. The accuracy discussion for these data is available in Liu (1996).

2.3 *Reclassification*

Because the four coarse resolution land cover maps over China derived from global datasets and the large-scale land use map of China have different classification systems, it is impossible to do an intercomparison. To facilitate the comparison, all the land cover/use maps were converted into a consistent classification system with seven types (table 2). The re-classified maps are illustrated in figure 1. In the conversion, the overall classification accuracy may be increased due to the common legend being coarser; some classification types that exist in the original legend do not exist in the new legend.

Table 2. The seven aggregated classes for the four 1-km products in China. The mosaic type is reclassified by aggregated reference data.

Class	Name	IGBP-DIS/ MODIS	UMd	GLC2000	Reference data
1	Forest/ woodlands	All forest, woody savannas	All forest, woodland	All forest	Forest, woods, other forest
2	Grass/ shrublands	All shrublands, savannas, grassland	All shrubland, wooded grassland, grassland	Bush, sparse woods, all meadow and all grassland	Shrubland, all grassland
3	Croplands	Croplands	Cropland	Farmland	Paddy land, dry land
4	Barren/ice	Snow and ice, barren or sparsely vegetated	Bare ground	Glacier, bare rocks, gravels, desert	Permanent ice and snow, sandy land, gobi, salina, bare soil, bare rock, others
5	Urban	Urban and built-up	Urban and built-up	City	All built-up
6	Wetlands	Permanent wetlands		Swamp, seaside wet lands	Swampland, beach and shore
7	Water bodies	Water bodies	Water	River, lake	Stream and rivers, lakes, reservoir and ponds, bottomland

2.4 *Method*

The large-scale land use map of China was used to evaluate the four land cover maps. We make a comparison between the reference map and four land cover maps from aspects including type area consistency and spatial consistency.

For the area consistency, we calculate the total area and area correlation coefficient of each aggregated class between the reference map and four land cover maps.

For the spatial consistency, we calculate the sub-fraction confusion matrix between the aggregated coarse resolution data and the corresponding high-resolution data at high-resolution level, i.e. after re-sampling the coarse resolution pixels into high-resolution pixels, and we then calculate the confusion matrix (Latifovic and Olthof 2004). The calculations of the sub-fraction confusion matrix are implemented in each sampling unit respectively (figure 2). To ensure a representative sample area, we randomly selected 21 sampling units with the help of the zoning map of land-use change of China in the 1990s. Each sampling unit has an area of 200 km $\times$ 200 km. All analyses performed in this study are based on a sub-fraction confusion matrix that has been generated using coarse resolution classification and high resolution reference land cover datasets.

3. Results and discussion

This section presents comparison results of four global land cover maps over China. In parallel to the presentation of accuracy assessment results, we discuss how the

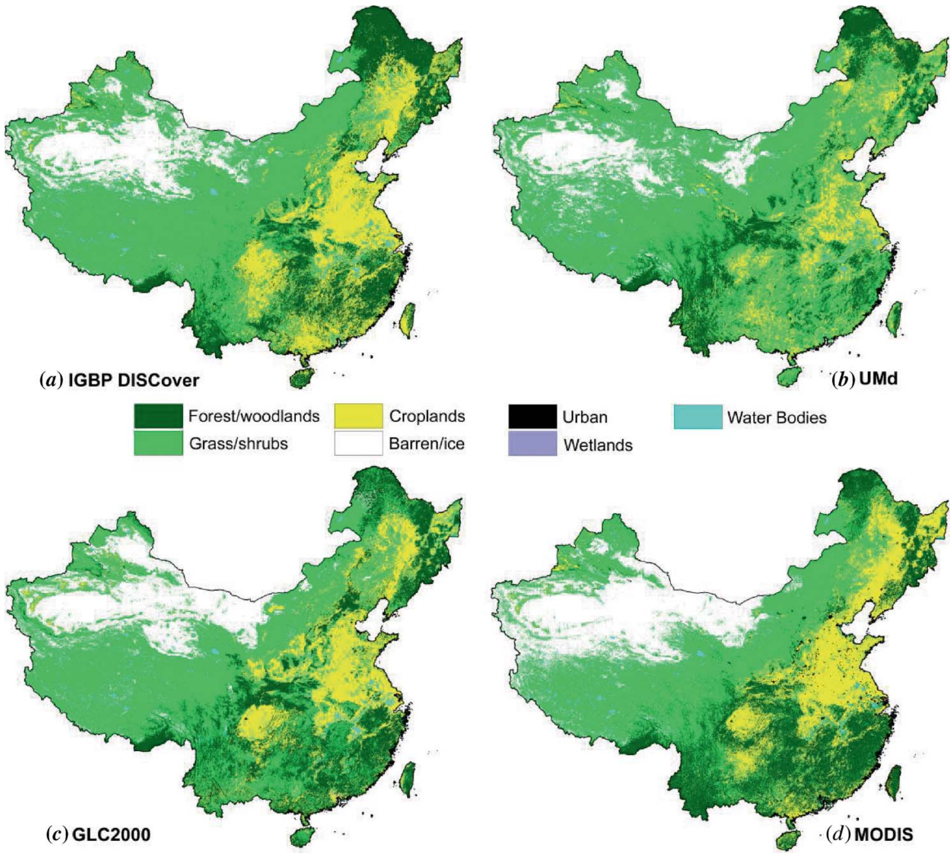

Figure 1. Land cover maps of the China landmass.

spatial distribution of classification error and type distribution of difference error sources, including the classification process and mixed pixel, affect the four global land cover maps over China. In the study, the discussion and conclusion given are based on the following assumptions:

- the four land cover maps are matched strictly in geo-registration with the reference map;
- all the legend conversions are correct; and
- the land cover changes in the period of 1990s to 2000 can be ignored.

3.1 *Area and spatial consistency comparison*

The areas for each aggregated class of the four datasets are summarized in figure 3. The areas are generally comparable. The areas of cropland in the four land cover maps are consistent; this may contribute to its obviously cultivating characteristics. The seasonal Normalized Difference Vegetation Index (NDVI) profiles of croplands in a year often show multi-peaks, double peaks and a single peak, so they are easier to identify than other land cover types. The areas of urban and water bodies are almost consistent because they can also be easily distinguished from vegetation types by using remote

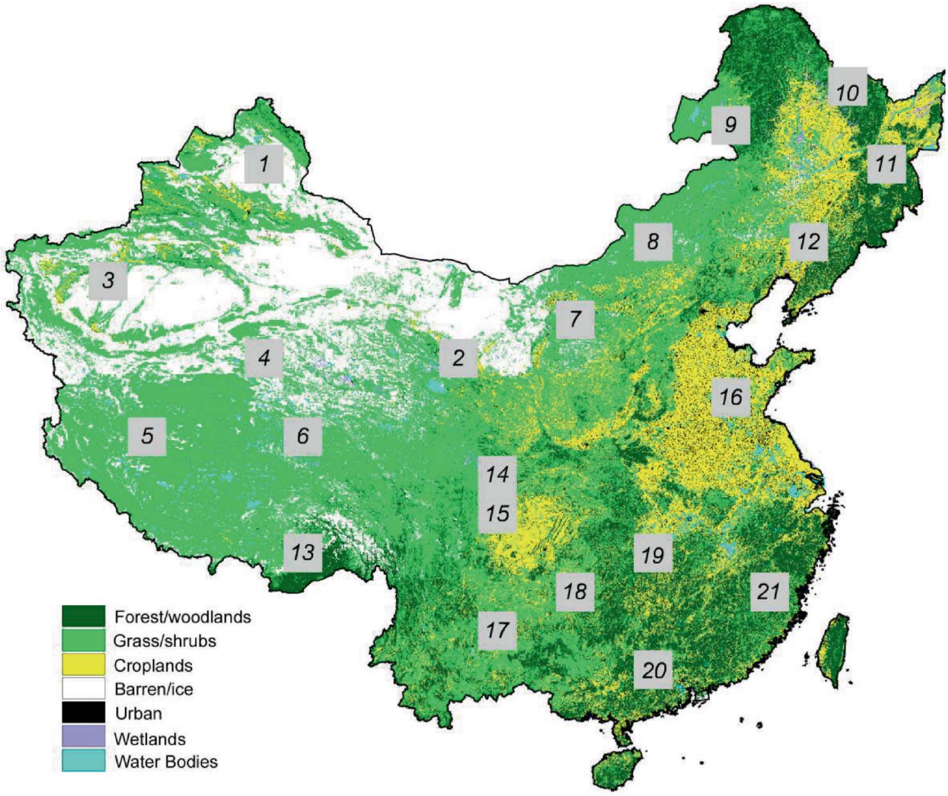

Figure 2. The distribution of the sampling units over a 1:100 000 land use map of the China landmass.

sensing data. The areas of grassland and shrub in the four land cover maps have a low consistency. The reason might be that grasslands and shrubs always have adjacent spatial distributions as well as similar spectral characteristics; therefore it is difficult to identify them by only using general vegetation indexes such as NDVI. We suggest that more classifiers could be combined with spectral methods to distinguish them. As for the correlation coefficients between the reference map and the four land cover maps, we found that the GLC2000 had the highest correlation with the reference data, with a correlation coefficient reaching 0.99, whereas the UMd had the lowest.

The spatial consistencies for each aggregated class of the four land cover products are summarized in table 3. The MODIS land cover product has the highest consistency with the reference data and its overall accuracy is 56.85%. The spatial consistencies of the other maps seem to correspond with their area comparisons.

3.2 *The spatial distribution of classification error*

Figure 4 presents the spatial distribution of classification error, which corresponds to the spatial distribution of the 21 sampling units. Each graph defines the accuracy relationship between each land cover product and the dominant land cover reference data. The reference dominant land cover accuracy is calculated between the 1-km resolution reference map converted from the high-resolution reference map and the

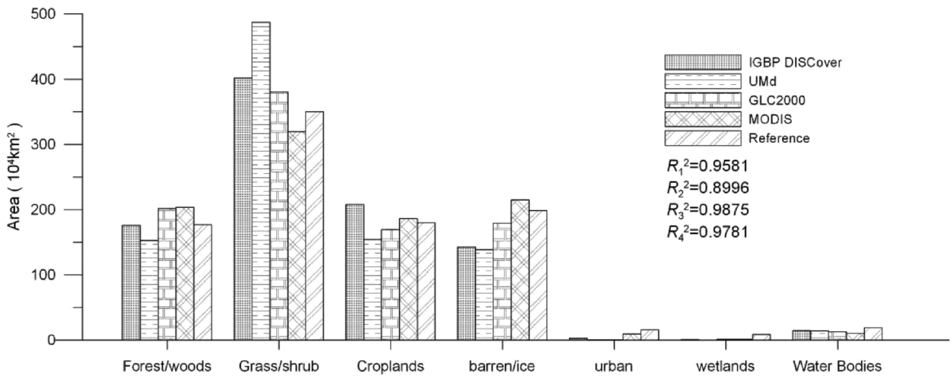

Figure 3. The total areas of the seven aggregated classes in China from the four 1-km products respectively. The R^2 values denote the type area correlation between the four land cover maps and the reference map, with the subscripts 1–4 corresponding to IGBP, UMd, GLC2000 and MODIS, respectively.

Table 3. Classification accuracies (%) based on the sub-fractional confusion matrix. The numbers 1–7 in the top row correspond to the land cover classes listed in table 2.

	Land cover class							
	1	2	3	4	5	6	7	Overall accuracy
IGBP	48.52	72.65	65.02	41.14	5.88	3.25	19.10	57.09
UMd	48.24	64.86	46.13	60.95	3.74	n/a	18.62	54.17
GLC2000	64.02	66.95	52.67	57.15	3.80	0.00	23.70	59.28
MODIS	57.23	59.69	65.09	54.71	13.39	1.31	18.09	56.85

high-resolution reference map itself. Each point in figure 4 represents the accuracy achieved over each sampling unit, where the value on the x-axis is the reference dominant land cover accuracy of each sampling unit, the value on the y-axis is the sub-fraction accuracy of each land cover product. The 1:1 line defines the maximum achievable accuracy for a given sampling unit, while the vertical distance between each point and the 1:1 line represents a classification method error, i.e. labelling error. The points with asterisks present the sampling units which have a minimum labelling accuracy less than 40%.

Figure 4 and table 3 show that the GLC2000 data have the highest labelling accuracy. In addition, the linear relationship of accuracy with the reference dominant land cover map is much stronger than other maps. The sampling unit 4 shows a relatively high labelling error in each map. Both the MODIS map and the IGBP land cover map have an obvious labelling error in sampling unit 1. Although there is no obvious labelling error in each sampling unit, the UMd data indicate a relatively low labelling accuracy among the four maps.

3.3 *The type distribution of error source*

Coarse spatial resolution data are inherently limited for mapping land cover over heterogeneous landscapes (Latifovic and Olthof 2004). Relative to the high resolution reference data, the mixed pixels form another primary error source besides labelling

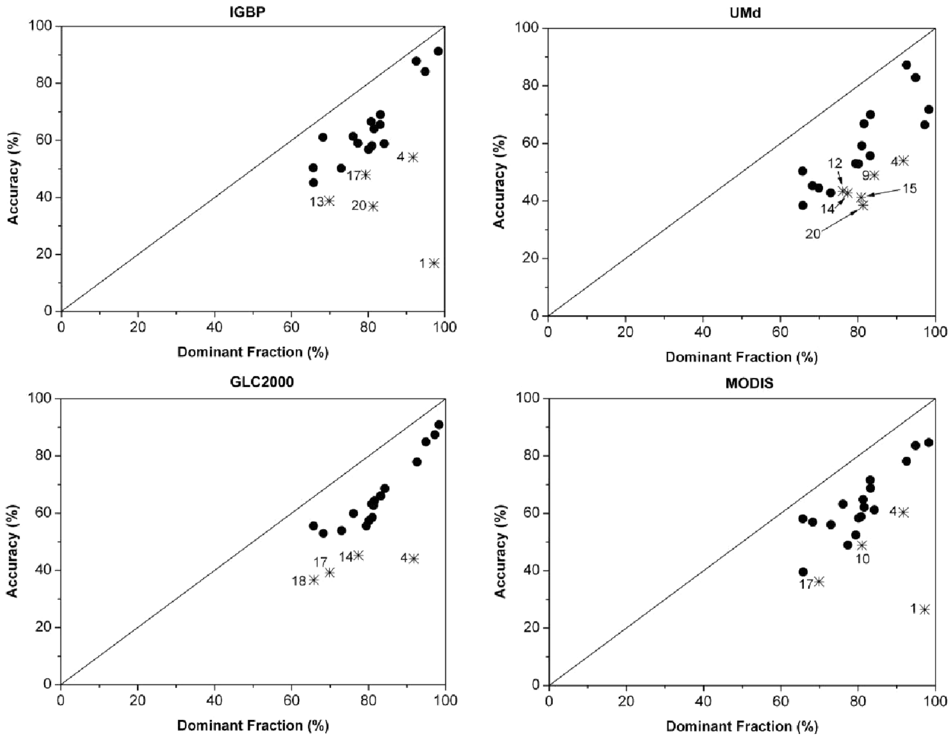

Figure 4. Spatial distribution of the classification accuracy for the four land cover products. The numbers next to the asterisks correspond to the numbers of the sampling units shown in figure 2.

errors. Figure 5 presents the labelling error and mixed pixel error separately for each land cover type. In the figure, the red colour represents the overall sub-fraction accuracy for each land cover type mentioned in table 3. The blue colour represents the percentage of the mixed pixel error, i.e. the accuracy of the dominant reference data is subtracted from the accuracy of high resolution reference data. The green colour represents the percentage of the labelling error.

Figure 5 shows that the labelling error and the mixed-pixel error have significant differences in different land cover types. The mixed pixel effect is very high in urban areas, accounting for 61.12%. The water bodies and wetlands classes make up 35.74% and 34.34% respectively. The wetland class has the highest labelling error because wetlands mainly distribute in transitional zones between grasslands and other land cover types and its spectral information is always mixed with the spectral signals of grassland. Among the four land cover maps, MODIS has the highest accuracy in the urban type. Other types such as forestland/woodland, grassland/shrubland, cropland and barren/ice illustrate similar error source structures. So we can improve the accuracy of land cover maps from two aspects, including the land cover quantitative expression approach and classification method.

4. Conclusions

The approaches implemented in the IGBP, UMd, GLC2000 and MODIS land cover maps are very different in the algorithms, input variables and classification

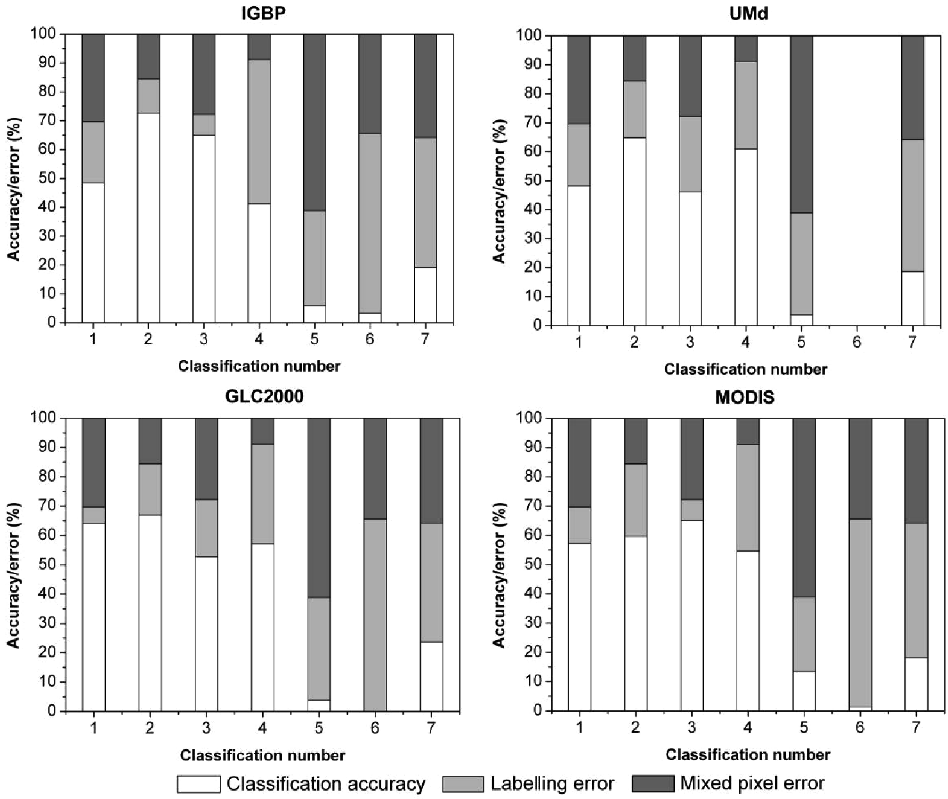

Figure 5. Classification accuracy, labelling error and mixed-pixel error for the four land cover products.

legends. We use the 1:100 000 land use database of China derived from Landsat TM/ETM images in 2000 as a reference to validate the four land cover maps based on a system with seven aggregated classes. The accuracy assessments include area and spatial consistency, and type distribution of error source. Based on the validation, we suggest that the accuracies of the four land cover products might not meet the requirement of land surface modelling. This study could give a preliminary overview for users to help them understand the differences in the four land cover products.

The results show that the GLC2000 land cover map represents the highest accuracy, but it has an obvious local labelling error and its labelling accuracy is zero for the wetland type. The MODIS land cover map ranks second for type area consistency and ranks third for sub-fraction overall accuracy compared with the reference data, which may be due to local labelling error. The IGBP land cover map indicates an appropriate labelling accuracy, although it has some local labelling error and type area inconsistency. Both the labelling accuracy and the type area consistency of the UMd land cover map are low, although it does not have an obvious local labelling error. Meanwhile, the area consistency is mainly controlled by the characteristics of land cover types. The urban and water bodies have the highest consistency in the area but have high mixed error among the four land cover maps.

Based on the dominant reference land cover data, we separate the mixed pixel error, labelling error and real classification accuracy at aggregated level for each product, which is a reflection of the improve potential of labelling accuracy for the four land cover maps. The quantitative results show that the different factors have different contributions to different land cover maps.

This study suggests there is a possibility of improving the accuracy of current large-scale land cover maps from two aspects, including the classification process and the land cover express approach. The labelling accuracy might be improved by combining multi-source information and the land cover express approach can engage the fuzzy logic-based approach. Information fusion technology might provide a better scheme for large-scale land cover maps, because the output of the information fusion system is the probability of each land cover type that can reduce the mixed pixel error. Furthermore, the information fusion system integrates multi-source data to improve labelling accuracy significantly.

As quoted by the International Society of Information Fusion (http://www.inforfusion.org/terminology.htm): 'Evaluating the reliability of different information sources is crucial when the received data reveal some inconsistencies and we have to choose among various options'. The 1:100 000 land use database is valuable but it misses some important type information such as evergreen, deciduous broadleaf and needle leaf forest in legend. Based on existing land cover maps, including the 1:100 000 land use database, a 1:1 000 000 vegetation map of China and the four land cover products, our further study will use the fuzzy decision analysis fusion technology, which develops a logic rule to make a choice between alternatives. This strategy might improve the accuracy of next-generation land cover maps of China.

Acknowledgments

This work is supported by the National Scientific Foundation of China (40871190), the Research Fund of State Key Lab of Resources and Environmental Information System, Chinese Academy of Sciences and the CAS International Partnership Project 'The Basic Research for Water Issues of Inland River Basin in Arid Region' (CXTD-Z2005-2). The China 1:100 000 land use dataset was provided by Environmental & Ecological Science Data Center for West China, National Natural Science Foundation of China (http://westdc.westgis.ac.cn). We also thank the anonymous reviewers for their extremely helpful and constructive comments on the manuscript.

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