Land cover classification over the Yellow River domain using satellite data

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Abstract

Land cover classification is implemented in the East Asian region using 250 m MODIS land surface reflectance product in combination with MODIS snow cover product and OLS human settlements product. This classification map is used as one of the input data of hydrological model applied to the Yellow River in China. The classification method is based on the decision tree classification by means of 11 kinds of land surface features derived from time series of two MODIS products and OLS data in 2000. The province based comparison of classification result with Chinese digital land cover map shows the good agreements in forest, agricultural field, grassland and barren categories. Another comparison with Chinese census resulte in the slight overestimations in forest and agricultural field. Agricultural sub-categories as paddy, dry field, and irrigated field shows relatively low agreements in both comparisons.

Keywords: Land cover; Decision tree classification; East Asia; MODIS products; OLS product

1. Introduction

Land cover classification over large area by means of remote sensing plays a important role not only in a thematic mapping but also in a geophysical modeling. Land cover is one of the critical parameters of the hydrological, biophysical, and climatological models to parameterize the geophysical, biological and ecological characteristics of land surface.

The purpose of this study is to create the land cover map of East Asia at the spatial resolution of 7.5 arc seconds using 250 m MODIS land surface reflectance product. Another two satellite derived products, 500 m resolution MODIS snow cover product and 1 km resolution DMSP (Defense Meteorological Satellite Program) human settlements product are used as auxiliary data to add the separability to some land cover categories. The primary application of this land cover map is hydrological modeling on the Yellow River in China. The Yellow River had been dried up and river water had not been reached to the Bohai Sea for many days in a year since 1970s. Since the main reasons of dry-up are the decrease of precipitation in upstream and excess water use mainly in agriculture, hydrological model, which can deal with the human activity such as water storage and irrigation as well as natural dynamics of water, has been developed based on the SVAT (Soil-vegetation-atmosphere transfer) scheme for the water management (Ma et al., 1998; Ma et al, 2000; Ma et al, 2002). Higher spatial resolution data of 250 m observed by MODIS is suitable for our purpose because the land cover of East Asia including the Yellow River basin is heterogeneous and it consist of small patches of land cover components such as forests, grasslands, agricultural fields etc. The land cover classification map derived in this study is used as the input data of this hydrological model to capture the area and distribution of land cover elements in the river domain.

2. Methods

2.1 Data

The three kinds of data were used for our classification. Two of them are "MODIS/Terra Surface Reflectance 8-Day L3 Global 250m SIN Grid version 4 (abbreviated as MOD09Q1)" and "MODIS/Terra Snow Cover 8-Day L3 Global 500m SIN Grid version 4 (MOD10A2)". MODIS has been operated since 1999 in order to provide global and long-term respective survey of the Earth (Salomonson et al., 1989) with 36 spectral bands allocated between 0.405 and 14.385 ? m. Third data is "Human Settlements data" included in the product "Nighttime Lights of the World - Change Pair" produced from nighttime brightness observed by OLS (Operational Linescan System) onboard DMSP.

Two MODIS products were acquired through the internet from EOS Data Gateway website (http://edcimswww.cr.usgs.gov/pub/imswelcome/). Although the target year of the classification is in 2000, 45 periods of MOD09Q1 and MOD10A2 from 26 February, 2000 to 18 February, 2001 except 12 August, 2000 are utilized for the classification because both data for the period from 1 January to 18 February in 2000 and MOD10A2 in 12 August were not available. These data are composite data constructed from 8 daily products for minimizing the cloud contamination, therefore the notation of "1 January" correspond to the data from 1 to 8 January. All periods of data were reprojected to Equirectangular (latitude/longitude) projection with the geographical coverage from 20 degree north to 50 degree north in latitude, and 90 degree east to 150 degree east in longitude by MODIS reprojection tool (http://edcdaac.usgs.gov/landdaac/tools/modis/index.asp). While original resolutions are 250 m and 500 m, the spatial resolution of reprojected MOD09Q1 is in 7.5 arc seconds and reprojected MOD10A2 is in 15 arc seconds, which correspond approximately to 230 m and 460 m at equator respectively. Human settlements data in 2000 was downloaded from DMSP site (http://dmsp.ngdc.noaa.gov/dmsp.html). Since the data is in Equirectangular projection with 30 arc seconds resolution, we just clipped the corresponding area.

2.2 Derivation of land surface features

The following eleven kinds of land surface features were derived as the input metrics of the classification:

1. Ann_Max_NDVI: Annual maximum NDVI.
2. Ann_Min_NDVI: Annual minimum NDVI.
3. Ann_Max_Ref1: Annual maximum band 1 reflectance.
4. Ann_Min_Ref1: Annual minimum band 1 reflectance.
5. Ann_Ave_Ref1: Annual average of band 1

reflectance.

6. Ann_Max_Ref2: Annual maximum band 2 reflectance.
7. Ann_Min_Ref2: Annual minimum band 2 reflectance.
8. Apr_Ave_NDVI: Monthly average of NDVI in April.
9. Jun_Ave_NDVI: Monthly average of NDVI in June.
10. Sum_Day_Snow: Number of snow days in summer.
11. Hum_Set_DMSP: DMSP Human settlements data.

The smoothed time series were derived by moving average of original NDVI (or reflectance) with the temporal window of seven periods in order to avoid the errors and unreasonable fluctuations. The annual maximum and minimum of NDVI and reflectance were selected from this smoothed time series. Since cloud and/or snow were found in some period and in some area, these undesirable data were excluded from sample of moving average by means of quality control flag included in MOD09Q1 and Maximum_Snow_Extent data in MOD10A2.

The Ann_Ave_Ref1 was derived by averaging of the samples from second maximum to second minimum reflectance among the cloud free and snow free reflectance, because maximum and minimum reflectance were excluded in order to avoid erroneous data. Apr_Ave_NDVI and Jun_Ave_NDVI were normal averages derived from cloud free reflectance in 4 periods of data from 6 April to 30 April and from 24 May to 17 June, respectively. Sum_Day_Snow was the number of snow days in summer season derived from Eight_Day_Snow_Cover data included in MOD10A2 product. Snow bits were accumulated through 11 periods of data fom 3 July to 29 September. Since the human settlements data is the averaged value of the year, no process but clipping was applied for Hum_Set_DMSP data.

2.3 Land cover categories

We embraced the IGBP (International Geosphere-Biosphere Programme) scheme as basic land cover categories, which is adopted by the Global Land Cover Characteristics (Loveland et al., 2000; Loveland &Belward, 1997) and MODIS land cover product (Justice et al., 1998). However, three modifications were made in order to meet our purpose of hydrological application. First, the agricultural area, just one category "Cropland" is defined in IGBP scheme, was divided to 5 sub-categories because agricultural fields play important role in water cycle in river basin, especially in the Yellow River basin where huge volume of water is used for irrigation. Second, mixed categories in IGBP scheme were excluded from our categories to keep the simplicity in our hydrological. Third, four categories were excluded in our classification because these categories exhibited similar characteristics in the current land surface features, and the feasibility study showed the difficulties in discrimination of these categories. Table 1 shows the land cover categories of this study and the correspondence to that of IGBP.

Table 1

Land cover categories with corresponding to IGBP categories.

IGBP land cover categories	The present study
Evergreen Needleleaf Forests	Evergreen Needleleaf Forests
Evergreen Broadleaf Forests	Evergreen Broadleaf Forests
Deciduous Needleleaf Forests	Deciduous Needleleaf Forests
Deciduous Broadleaf Forests	Deciduous Broadleaf Forests
Mixed Forests	-----------
Closed Shrublands	-----------
Open Shrublands	Open Shrublands
Woody Savannas	-----------
Savannas	-----------
Grasslands	Grasslands
Permanent Wetlands	-----------
Croplands	Croplands (including paddy)
Croplands	Croplands (non-paddy)
Croplands	Double-cropping Fields (including paddy)
Croplands	Double-cropping Fields (non-paddy)
Croplands	Irrigated Fields
Urban and Built-up Lands	Urban and Built-up Lands
Cropland/Natural Vegetation Mosaics	-----------
Snow and Ice	Snow and Ice
Barren	Barren
Water Bodies	Water Bodies

2.4 Classification method

The classification based on the decision tree method by means of land surface features described above was adopted due to the following advantages: (1) it is easy to customize the classification structure (shape of tree) by arranging the module which consist of input data and decision criteria, (2) it can control the classification result explicitly and easily by adjusting the threshold used in criteria, (3) it is robust to the noises in input data such as clouds if the noises were outside of the scope of decision module, and (4) it is capable to derive the stable classification result for another year due to the stability of the input data.

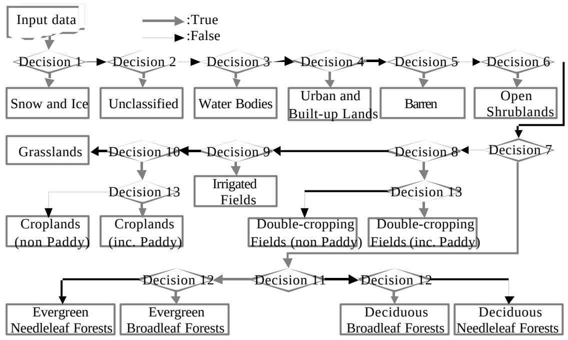
2.4.1 Pre-processing

Since MOD09Q1 product is one of the land product, no data are included over the deep ocean, furthermore, the pixels around the border of deep ocean are subject to have higher reflectance which is believed to be clouds or sea ices. Therefore, deep ocean and its border (4 pixels) were masked using image handling software and categorized to Water Bodies.

2.4.2 Decision tree classification

Fig. 1 shows the processing flow of the classification method and criteria used in each decision steps. Snow and Ice category is extracted in decision 1 using Sum_Day_Snow data. Erroneous pixels are excluded in decision 2. The main reason of the error is that at least one of land surface features could not be derived due to the cloud or snow. Water Bodies are discriminated using Ann_Min_Ref2 with the general characteristics that reflectance of water is much lower than that of land surface in near infrared wavelength. However, Ann_Min_Ref2 shows relatively higher reflectance near river mouth of large rivers as Chang Jiang River and the Yellow River. Therefore, another criterion based on Ann_Min_NDVI was added in order to avoid the misclassification of water to the land over these region. Since land surface except permanent snow and ice regions will pass through the previous decision steps, the following decisions are applied to the land area. Urban and Built-up Lands is generally difficult to discriminate from non and low vegetated area since these shows the similar features both in reflectances and NDVI. Therefore Hum_Set_DMSP was added as the criterion, and pixel with lower Ann_Max_NDVI and higher Hum_Set_DMSP is classified to Urban and Built-up Lands. Barren and Open Shrublands, where the vegetation coverage is constrained by climatic, geologic, or other various conditions, are extracted by means of Ann_Max_NDVI, which shows the most active status of vegetation in the year. Ann_Ave_Ref1 is applied in order to discriminate the herbaceous type and tree type vegetation in decision 7 on the basis that the tree type vegetation shows generally darker reflectance in visible wavelength compared to herbaceous type vegetation.

The herbaceous type vegetations are classified to grassland or five kinds of agricultural fields. Double-cropping Fields are extracted in decision 8 by means of simultaneous use of Apr_Ave_NDVI and Jun_Ave_NDVI. The first cropping season is from February to May, and second season is from July to middle of November in this region, that is, NDVI in June is lower than that of April in this region. This characteristics is quite unique from the phenological and hydrological point of view, compared to natural grasslands or single cropping agricultural lands. The pixel is consequently labeled as paddy or non-paddy in decision 13 according to the Ann_Min_Ref1 criterion. The three criteria used for Irrigated Fields in decision 9 were derived fully empirically by investigation of the feature images. Passed pixels will be classified to Croplands or Grasslands according to Ann_Max_Ref1 criterion. If the reflectance in visible wavelength is lower than the threshold, the pixel is categorized to the Croplands, and higher is to Grasslands. This criterion is also derived empirically based on the rough assumption that agricultural field has darker reflectance in several periods of year than natural grassland. The pixel categorized in Croplands are labeled as paddy and non-paddy by same criterion applied to the Double-cropping Fields.



Decision	Criteria	Thresholds
1	Sum_Day_Snow > Threshold	15 days
2	Metrics 1~6 include error	None
3	Ann_Min_Ref2 < Threshold OR Ann_Min_NDVI < Threshold	5.00 % -0.05
4	Ann_Max_NDVI < Threshold AND Hum_Set_DMSP > Threshold	0.45 55
5	Ann_Max_NDVI <= Threshold	0.15
6	Ann_Max_NDVI <= Threshold	0.25
7	Ann_Ave_Ref1 <= Threshold	5.50 %
8	Metrics 7-1,7-2 have no error AND (Apr_Ave_NDVI - Jun_Ave_NDVI) > Threshold	None 0.00
9	arctan(Ann_Max_NDVI/Ann_Min_NDVI) >= Threshold AND Ann_Min_NDVI < Threshold AND Ann_Max_Ref1 < Threshold	74.0 deg. 0.15 25.0
10	Ann_Max_Ref1 < Threshold	10.5 %
11	Ann_Min_NDVI > Threshold	0.44
12	Ann_Max_Ref2 > Threshold	28.0 %
13	Ann_Min_Ref1 < Threshold AND	3.75 %

Fig. 1 Flowchart of decision tree classification and criteria in each decision step.

The tree type pixels are classified to four forest categories, "Evergreen Needleleaf Forests", "Evergreen Broadleaf Forests", "Deciduous Needleleaf Forests", and "Deciduous Broadleaf Forests", according to the seasonality and leaf type. Seasonality is determined by Ann_Min_NDVI criterion, which shows the least active status of vegetation in the year. Leaf type is measured by Ann_Max_Ref2, that is, brighter forest in near infrared wave region is classified to broadleaf, and darker is to needleleaf.

The determination of the thresholds is critical issue with regard to the classification accuracy, since it directly controls the classification result. We decided the each thresholds by means of following two methods. MODIS land cover product (abbreviated as MOD12Q1) was used as the training data for decisions 3, 5, 6, 7, 11 and 12 as first method. Individual land surface features were sampled every four pixels in order to overlay to MOD12Q1, and training data were extracted by each land cover area in MOD12Q1. The thresholds were derived from the comparison of pixel based histograms of each category. Another method was simple visual interpretations. The thresholds in decision 1, 4, 8, 9, 10, and 13 were derived manually with reference to existing land cover maps using commercial image handling software.

2.5 Accuracy assessment

The classification result was compared to two types of reference data with Chinese province base.

One reference is existing digital land cover map, "1 km land-use & land cover raster data of China (abbr. as CASW data)" provided by CASW Data Technology Co., Ltd. (http://www.casw.com.cn/). Land cover percentage of 25 land cover type within 1 km grids in 1996 are derived from Landsat images. This data was geometrically re-projected to the same projection as our land cover classification map in the resolution of 30 arc seconds, thereafter, the pixel are aggregated to the province using province boundary data. The land cover categories in both classification map were aggregated to 6 general categories (forest, agricultural land, grassland, barren, paddy field, and dry field) as following:

The present study:

Forest; Evergreen Needleleaf Forests, Evergreen Broadleaf Forests, Deciduous Needleleaf Forests, and Deciduous Broadleaf Forests

Agricultural field; Croplands (inc. paddy), Croplands (non-paddy), Double-cropping Fields (inc. paddy), Double-cropping fields (non-paddy), and Irrigated Fields

Grassland; Grasslands

Barren; Barren

Paddy field; Croplands (inc. paddy) and Double-cropping fields (inc. paddy)

Dry field; Croplands (non-paddy), Double-cropping fields (non-paddy), and Irrigated Fields

CASW data:

Forest; woodland, sparse woodland, and other woodland

Agricultural field; dry land and paddy field

Grassland; low-, medium-, and hi-covered grassland

Barren; gobi desert, barren land, barren rock, and sand ground

Paddy field; paddy field

Dry field; dry land

Another reference is Chinese census data. Province based land cover area of aggregated four categories (forest, agricultural field, paddy field, and irrigated field) are compared to two kinds of census data. Forest area is obtained by counting the area of needleleaf forest, broadleaf forest, commercial forest, and bamboo grove in the 4th Chinese census of forest resources (1989~1993) derived from Chinese Forest Science Data Center website (http://www.cfsdc.org/). Agricultural field, paddy field and irrigated field were based on the total planted area, paddy area, and effective irrigated area in 2000, respectively, derived from National Bureau of Statistics of China website (http://www.stats.gov.cn/). Area of forest, agricultural field, and paddy field of the classification are same as aggregated categories in previous comparison with existing land cover map. Irrigated field is total area of Croplands (inc. paddy), Double-cropping Fields (inc. paddy), and Irrigated Fields. Five provinces, Heilongjiang, Inner Mongolia, Tibet, Xinjiang, and Hainan were excluded from the comparison, since our classification map do not cover the whole area of these provinces.

3. Results and discussion

3.1 Classification result

Fig. 2 shows the classification result. Clear zonal distribution of Barren, Open Shrublands, Grasslands, Croplands, and Forests appeared from the inner continent up to Pacific Ocean. Barren correspond to Gobi and Taklamakan Desert. Open Shrublands was found in transition zone of barren and grassland. This category was sensitive to the threshold value, and boundary changed significantly by the threshold value of Ann_Max_NDVI. it is inferred that inter-annual variation is also large in this region since vegetation in semi-arid region is sensitive to climate condition. Grasslands spread in Mongolia, Russia, and north eastern to south western China, surrounding the open shrublands. Forests were distributed in most outer zone mainly near Pacific Ocean: northern Mongolia, eastern Siberia, Korean Peninsula, Japan, southern China, and South East Asian countries to India. Evergreen forests were dominated by broadleaf forest rather than needleleaf forest. Evergreen Broadleaf Forests were found in tropical to subtropical zone, subarctic zone, and Japan. Evergreen Needleleaf Forests were found in mountainous zone such as Himalaya Mountains and Sikhote Alin Mountains in eastern Russia. Deciduous Broadleaf Forests are distributed in Gansu, Sichuan, and Hunan provinces in China, where the northern boarder of subtropic evergreen forests, and also distributed in north eastern China around Liaoning and Jilin provinces, and Korean Peninsula where the southern border of subarctic evergreen forests. Five kinds of Croplands were widespread between grassland and forest filling the gap of intricately distributed forests. Paddy fields indicators were appeared dominantly South to South Eastern Asian countries, southern China, and North Eastern China Plain. Double-cropping Fields, which consist both of paddy and non-paddy fields, were found in downstream including the North China Plain and Wei Basin in Shaanxi province where one of the branch of the Yellow River, Wei River flows. A number of large irrigated districts including two huge districts of Ningxia and Hetao were extracted in upstream of the Yellow River. The distribution of irrigated and double cropping fields showed better agreement with Chinese irrigation map (Prof. Jianyao Chen, personal communication) shown in Fig. 3, even though the irrigation map indicates just the Yellow River basin and irrigated area in mid and downstream was categorized in Double-cropping Fields in our classification. Unclassified data, which were mainly due to the cloud, clustered around Himalaya Mountains where it could be frequently cloudy or cloud detection algorithm seems to confuse the cloud with the snow.

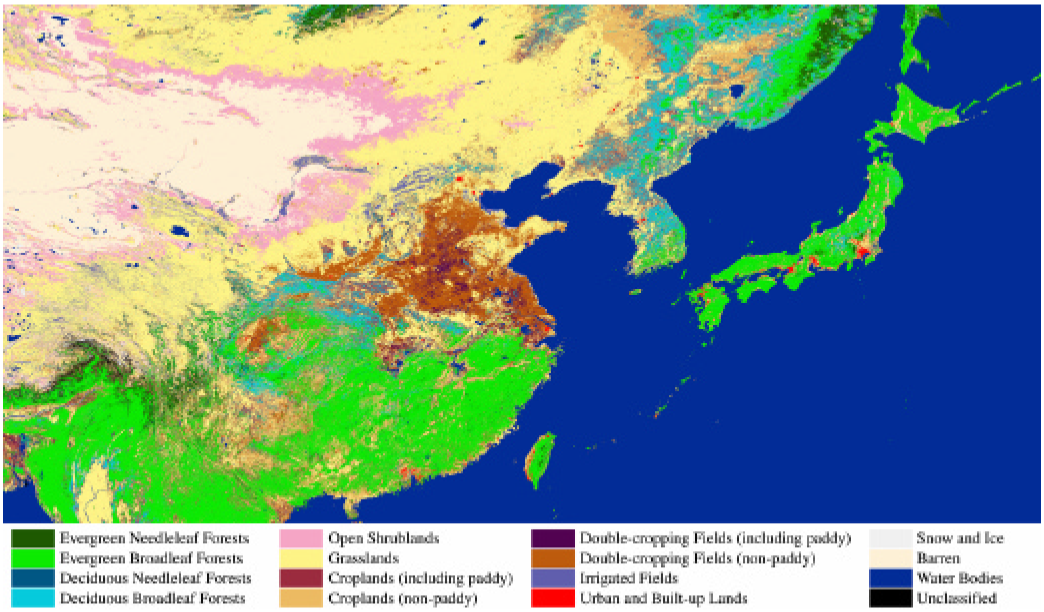


Fig. 2 Land cover classification result

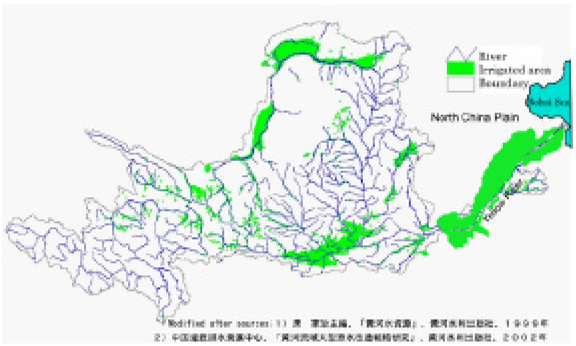


Fig. 3 Irrigation map of the Yellow River basin (Prof. J. Chen, personal communication).

3.2 Comparison with Chinese land cover map

Fig. 4 shows the Chinese province map, and Fig. 5 shows the scatter diagrams of land cover area by Chinese provinces. Unfortunately no information was obtained about the accuracy of CASW data.

Fig. 4 Chinese province map.

The comparison showed the good agreements in Forest, Agricultural Field, Grassland, and Barren, but low agreements two agricultural sub-categories, Paddy field and Dry field. The strong geographical dimensions were found in all the categories. Forest area was underestimated in north eastern provinces (Inner Mongolia, Liaoning, Heilongjiang, and Jilin) but overestimated in south eastern provinces (Sichuan, Hunan, Fujian, and Jiangxi). Agricultural field was underestimated in north eastern provinces (Inner Mongolia, Liaoning, and Jilin) but overestimated in south western provinces (Qinghai, Guizhou, Yunnan, and Tibet). Grassland was underestimated in western provinces (Qinghai, Inner Mongolia, Xinjiang, and Tibet) but overestimated in north eastern provinces (Heilongjiang, Jilin, Liaoning, and Hebei). Barren was underestimated in south western to central provinces (Tibet, Sichuan, Shaanxi, and Yunnan) but overestimated in western provinces (Inner Mongolia, Qinghai, Xinjiang, and Gansu). Paddy field was underestimated in central to eastern provinces (Hunan, Jiangxi, Anhui, Jiangsu, and Guangdong) but overestimated in north eastern provinces (Heilongjiang and Inner Mongolia) and Yunnan province, provinces with larger paddy field were generally underestimated and vice versa. Dry field was underestimated in northern to eastern provinces (Inner Mongolia, Jilin, Gansu, and Shandong) but overestimated in southern provinces (Tibet, Guangxi, and Yunnan).

From geographical viewpoint, north eastern provinces showed the underestimation in forest, agricultural field and dry field, but overestimation in paddy and grassland. Central to eastern provinces where the forest was overestimated showed the underestimation in paddy fields. The province where grassland was underestimated exactly corresponded the overestimated provinces in barren, and these provinces have larger area both of grassland and barren. Geographical distribution in these provinces showed the clear zonal distribution of Barren, Open Shrublands, and Grasslands in our classification. The discriminations of these three categories resulted in overestimation in barren and underestimation in grassland.

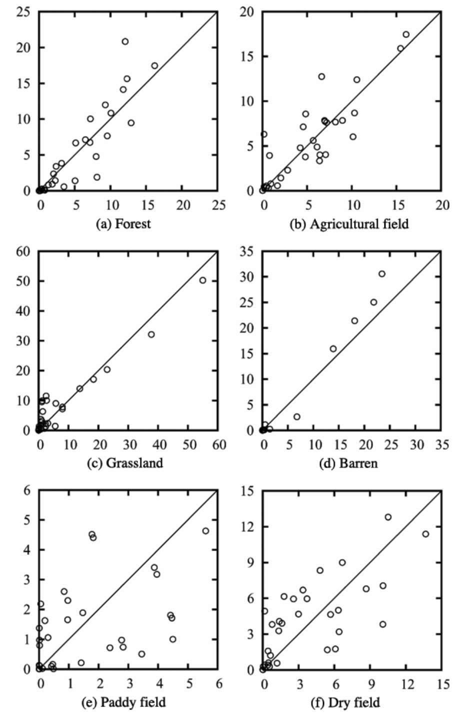


Fig. 5 Comparison of classification result with CASW data. Horizontal axis is land cover area of Chinese provinces in 10000 km^2 derived from CASW data and vertical axis is same but derived from classification.

3.3 Comparison with Chinese census

Fig. 6 shows the scatter diagrams of land cover area in each Chinese provinces derived from ground based census and our classification.

Forest and agricultural field showed less agreements relative to previous comparison with land cover map. Our classification overestimated nearly double of census data in forest and agricultural field, even though the geographical dimensions were similar. Other studies also resulted in the overestimation of classification based land cover area for forest (Hansen et al., 2000), and for agricultural and irrigated area (Frolking et al., 1999). The comparison of land cover area between classification and ground based or registration based census, which is appropriate to be called as "land use" rather than "land cover", is complicated due to the difference in recognition of the land surface. Furthermore, coarse resolution data generate the mixture of land cover in one pixel especially in the heterogeneous land cover. Several kinds of land cover as farm roads and open spaces relevant to agricultural field are included in one pixel with the spatial resolution of 7.5 arc seconds, even it is classified as agricultural field.

The area of paddy field in two reference data were less consistent, and area in census was smaller than that in existing land cover map, this was also pointed out by Frolking et al. (2002). However, the geographical dimension was similar in both comparison i.e. central to eastern provinces showed the underestimation, and north eastern provinces showed the overestimation.

The irrigated area is underestimated in the North China Plain such as Shandong, Hebei, Jiangsu, and Hunan province. This underestimation was due to the discrimination of paddy field from double-cropping field. The overestimated provinces were Qinghai, Shanxi, Sichuan, Yunnan, etc. The extraction of Irrigated Fields category caused the overestimation in former two provinces, and discrimination of paddy fields from cropland in latter two provinces.

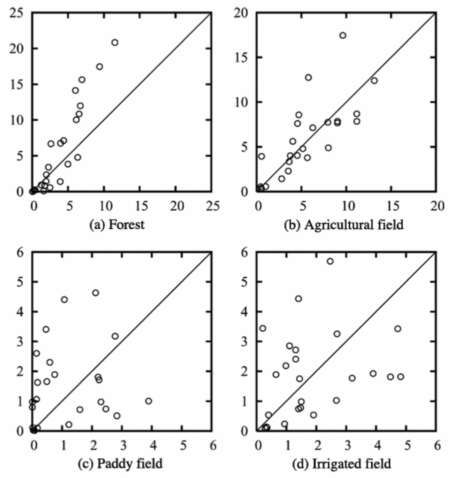


Fig. 6 Comparison of classification result with Chinese census. Horizontal axis is land cover area of Chinese provinces in 10000 km^2 derived from census and vertical axis is same but derived from classification.

4. Conclusions

Land cover classification map for East Asia region in 2000 was produced by means of two kinds of MODIS land products and one OLS product in order to be applied to a hydrological model. The classification method was based on the simple decision tree method using eleven land surface feature images witch represent the spectral and phenological characteristics of land surface. The decision tree method is so flexible that we can develop the purpose-designed classification tree by arranging the modules which consist of input images and decision criteria. Additionally, It is robust for the local noises due to clouds or snows, if the noise arises at the out of classification interest. We used the two kinds of MODIS land products, Surface Reflectance 8-Day L3 Global 250m SIN Grid (MOD09Q1) and Snow Cover 8-Day L3 Global 500m SIN Grid (MOD10A2), as input data because their high spatial resolutions are suitable for East Asia where the land surface is much heterogeneous composed of small land cover units. We selected the fifteen land cover categories, ten of them were acceded to the IGBP classification scheme and other five agricultural categories: croplands (including paddy), croplands (non-paddy), double-cropping fields (inc. paddy), double-cropping agricultural field (non-paddy) and irrigated fields were selected because of their hydrological importance. The thresholds in the classification process are essential factors to control the classification result. We used the MODIS land cover product and existing land cover maps for determining the thresholds owing to the restricted availability of training data. The comparison of the aggregated six categories with existing Chinese land cover map showed the good agreements in forest, agricultural field, grassland, and barren categories, but low agreements in agricultural sub-categories, paddy fields and dry fields. The another comparison of forest, agricultural field, paddy field, and irrigated fields with Chinese province based census indicated the overestimation in forest and agricultural field, and poor correlation in paddy field and irrigated field. Accuracy assessment of the classification result is complicated task by reason of absence of proper references. The comparison between classification maps or ground based survey is affected to some extent by the incidental factors as spatial resolutions, data source, and the name and definition of the category, rather than classification itself. Nevertheless, the comparison is useful for the improvement in the method and parameters, and it shows us the way to the most reasonable result. The acquisition of effective input data in discriminating the land cover type and adjustment of the thresholds by means of ancillary information as high resolution satellite image are required for further progress in this study.

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