

Vegetation classification of East China with multi-temporal NOAA-AVHRR data

LI Junxiang (✉), DA Liangjun, WANG Yujie, SONG Yongchang

Department of Environmental Science, East China Normal University, Shanghai 200062, China

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Abstract East China lies in the subtropical monsoon climatic zone and is dominated by subtropical evergreen broad-leaved forests, a unique vegetation type mainly distributed in East Asia with the largest distribution in China. It is important to be able to monitor and estimate forest biomass and production, regional carbon storage, and global climate change impacts on these important vegetation types. In this paper, we used coarse resolution remote sensing data to identify the vegetation types in East China and developed a map of the spatial distribution of vegetation types in this region. Nineteen maximum normalized difference vegetation index (NDVI) composite images (acquisition time span of 7 months from February to August), which were derived from 10 days National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) channel 1 and channel 2 observations, an unsupervised classification method, and the ISODATA algorithm were employed to identify the vegetation types. To reduce the dimensions of the dataset resulted in a total of 28 spectral clusters of land-cover of which two clusters were urban/bare soil and water, the images were processed using principal component analysis (PCA). The 26 remaining spectral clusters were merged into six vegetation types using the Chinese vegetation taxonomy system: evergreen broad-leaved forest, coniferous forest, bamboo forest, shrub-grass, aquatic vegetation, and agricultural vegetation. The spatial distribution and areal extent for the coniferous forests, shrub-grass, evergreen broad-leaved forests, and agricultural vegetation were calculated and compared with the Vegetation Atlas of China at a 1:1,000,000 scale. The spatial accuracy and the area accuracy for coniferous forests, shrub-grass, evergreen broad-leaved forests, and agricultural vegetation were 79.2%, 91.3%, 68.2% and 95.9% and 92.1%, 95.9%, 63.8% and 90.5%, respectively. The spatial accuracy and area accuracy of the bamboo forest

were 28.7% and 96.5%, respectively; the spatial accuracy of aquatic vegetation was 69.6%, but there was a significant difference in its area accuracy because image acquisition did not cover the full year. Our study demonstrated the feasibility of using NOAA-AVHRR to identify the different vegetation types in the subtropical evergreen broad-leaved forest zone in East China. The spatial location of the six identified vegetation types agreed with the actual geographical distribution of the vegetation types in East China.

Keywords vegetation classification, remote sensing, NDVI, principal component analysis, East China

1 Introduction

It is very important to identify the terrestrial vegetation information to study vegetation ecology, net primary productivity (NPP), biodiversity conservation, and regional ecological securities, especially in the current global climate change, anthropogenic environment stresses, and the impacts of natural disasters on terrestrial ecosystems in various scales. It is a great challenge that how we can acquire information on terrestrial ecosystem timely, rapidly, precisely, and dynamically. For such reasons, the traditional vegetation investigation methods can not obviously meet such requirements. The remote sensing, however, a unique way in which land surface information can be acquired in various scales, can satisfy the land-use and land-cover classification in large scale.

The measurements of remote sensing in visible bands and thermal infrared can be used to extract characteristics of land-cover, to derive biophysical parameters of vegetation, and to support many study fields including global change (Running et al., 1994). The National Oceanographic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) data, for its high temporal resolution (two times daily) and moderate spatial resolu-

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E-mail: jxli@des.ecnu.edu.cn

tion (1.1km near-nadir), can be employed in land-cover classification at regional or global scale (Moody and Strahler, 1994; Sellers et al., 1994). It can also be used to support studies in many study fields which cover from regional to global scale, including many international joint research programs such as International Geosphere-Biosphere Program (IGBP), International Global Atmospheric Chemistry project (IGAC), Biospheric Aspects of the Hydrological Cycle (BAHC), and Global Change and Terrestrial Ecosystems (GCTE) in which the NOAA-AVHRR data are the important information sources (Ehrlich et al., 1994). At present, there are three remote sensing data, NOAA-AVHRR, SPOT-Vegetation (VGT) (Mayaux et al., 2000; Xiao et al., 2002) and Terra's MODIS (Moderate Resolution Imaging Spectroradiometer). They can be used to acquire 1-km spatial resolution land-cover data sets for vegetation classification in broad scale. However, for land-cover classification in large area, the most frequently used remote sensing data are the NOAA-AVHRR and/or NDVI derived from NOAA-AVHRR (Defries and Townshend, 1994; Eidenshink and faundeen, 1994; Sellers et al., 1994; Townshend, 1994; Townshend et al., 1994; Cihlar et al., 1996).

There are many studies about the vegetation classification with remote sensing data in regional and global scale (Zhu and Evans, 1994; Achard and Estreguil, 1995; Sheng et al., 1995; Boyd and Ripple, 1997; Li and Shi, 1999), most of which used the NDVI from NOAA-AVHRR or combined other AVHRR channel's data. However, there are only few studies focused on the vegetation classification in subtropical evergreen broad-leaved forest zone for their unique geographic distribution in East Asia, mainly in China. So, it is of great significance to do vegetation classification in the subtropical evergreen broad-leaved forest zone in China. Our objectives were to (1) identifying the vegetation types in East China with multi-temporal NOAA-AVHRR NDVI data; (2) mapping vegetation types and providing spatial distribution data for the studies on climate change, forest biomass and NPP estimations, and carbon sequestration and simulation in East China.

2 Data processing and classification methods

2.1 Data and data processing

The study area covers East China, which includes Anhui province, Jiangxi province, Jiangsu province, Fujian province, Zhejiang province, and Shanghai City.

The data used for the vegetation classification of East China are the time-series NDVI composite imagery data derived from NOAA-AVHRR channel 1 and channel 2. The NDVI data were used for its high proportioned relationship to plant photosynthesis activity (Sellers, 1987), and the integral NDVI to time is related to plant aboveground biomass (Tucker et al., 1985a; Tucker et al., 1985b; Goward and Huemmrich, 1992; Running et al., 1994). The data acquisition time was from February to August, 1995. The in-

terval of maximum NDVI composition was 10 days. For some reasons, there were lack for the scenes of the first 10 days of March and August, and so there were 19 scenes of maximum NDVI composite imageries totally.

The data were provided by EDC (Earth Resources Observation System (EROS) Data Center) of USGS. The AVHRR data received by ground station were processed as follow: (1) the atmospheric correction and radiation remediation of channel 1 and channel 2; (2) coarse geometrical rectification of the imagery; (3) elimination of cloud contamination with maximum composite criterion; (4) cloud screening (using the method of maximum composite criterion). The near-nadir cloud-free maximum NDVI cells were selected from 10 days measurements to composite a cloud-free maximum NDVI composite image. These procedures were done by EDC.

The vector boundary of five provinces and one city were digitized from topographic maps which was registered to the same projection and geodatum used for NDVI composite imagery geometrical rectification to ensure the close match between the vector data and rectified NDVI raster imageries.

First, the 19 single-band NDVI imageries were merged into one multi-channel imagery, then the coarse study area was cut down from the imagery, and then the geometrical rectification of the cut-down imagery was conducted using 29 ground control points (GCPs) selected from 1:500 000 topographic maps. The rectification regime was cubic polynomial, and cubic convolution was employed in pixel resampling. The root mean square (RMS) of the imagery was 0.01–0.03 pixels after rectification. Finally, the vector boundary of the study area was overlaid on the rectified imagery, and the precise area was delimited and cut down based on the vector boundary for classification.

Principal component analysis (PCA) is very useful for reducing the dimensions of the data and frequently used to process multi-temporal series NDVI data (Cihlar et al., 1996). The PCA was used to process the cut-down 19-band imagery to reduce the dimensions of the data sets, the first three components, loading more than 99.1% information of the 19-band composite NDVI imagery, was then used for vegetation classification ultimately. The statistical character and information weight loading of each component could be seen from Table 1.

2.2 Classification method

The classification regime of the imagery was unsupervised classification, and the ISOCCLASS algorithm was used. During the unsupervised classification processes, the number of clusters was set from 15 to 35 arbitrarily. For all classification results, each cluster was checked preliminarily with field investigation data, and the vegetation and land-use maps, then the suitable number of clusters was confirmed. Finally, the vegetation type of each cluster was defined based on the field investigation data, and vegetation

and land-use maps.

Table 1 Statistical trait of 19 maximum NDVI composite imageries after PCA processing

com- ponents	Correlation eigenvector	Cumulative contribution/%	Covariance eigenvector	Cumulative contribution/%
PC1	18.620	98.000	247 763.44	98.058
PC2	0.151	98.795	1952.86	98.831
PC3	0.058	99.1	741.93	99.124
PC4	0.034	99.279	434.73	99.296
PC5	0.026	99.416	329.55	99.427
PC6	0.020	99.521	243.69	99.523
PC7	0.014	99.595	191.44	99.599
PC8	0.012	99.658	151.07	99.659
PC9	0.011	99.716	132.53	99.711
PC10	0.009	99.763	123.20	99.760
PC11	0.008	99.805	107.16	99.823
PC12	0.007	99.842	91.18	99.839
PC13	0.006	99.874	85.65	99.873
PC14	0.005	99.900	69.38	99.900
PC15	0.005	99.926	68.20	99.927
PC16	0.004	99.947	57.38	99.950
PC17	0.004	99.968	50.92	99.970
PC18	0.003	99.984	38.43	99.985
PC19	0.003	100.000	37.69	100.000

2.3 Accuracy assessments

It was difficult to assess the vegetation classification accuracy with coarse (1-km resolution) remote sensing data in regional and global scale. There are three ways in general to test the vegetation classification results (checking results with the in situ investigation data; validating with the existing map materials, i.e. vegetation map, land-use map, etc.; using classification results with higher spatial resolution remote sensing data, such as Landsat-TM/ETM+ to validate). The first was infeasible because of its large workloads and field sampling numbers for vegetation/land-use classification accuracy assessments in regional and global scale. For the sake of limitations in both time and conditions, it was difficult to conduct detail field survey and sampling to support broad-scale vegetation/land-use classification validations, so the latter two methods were frequently used to test the accuracy assessments for the coarse spatial resolution remotely-sensed classification results (Achard et al., 2001; Xiao et al., 2002). In this study, the digitalized vegetation map from Vegetation Atlas of China (hereafter called the Atlas) (Hou, 2000) was used to evaluate the accuracy assessment references.

3 Results and analysis

3.1 Cluster identification

For each ISODATA classification result from 15 to 35 clus-

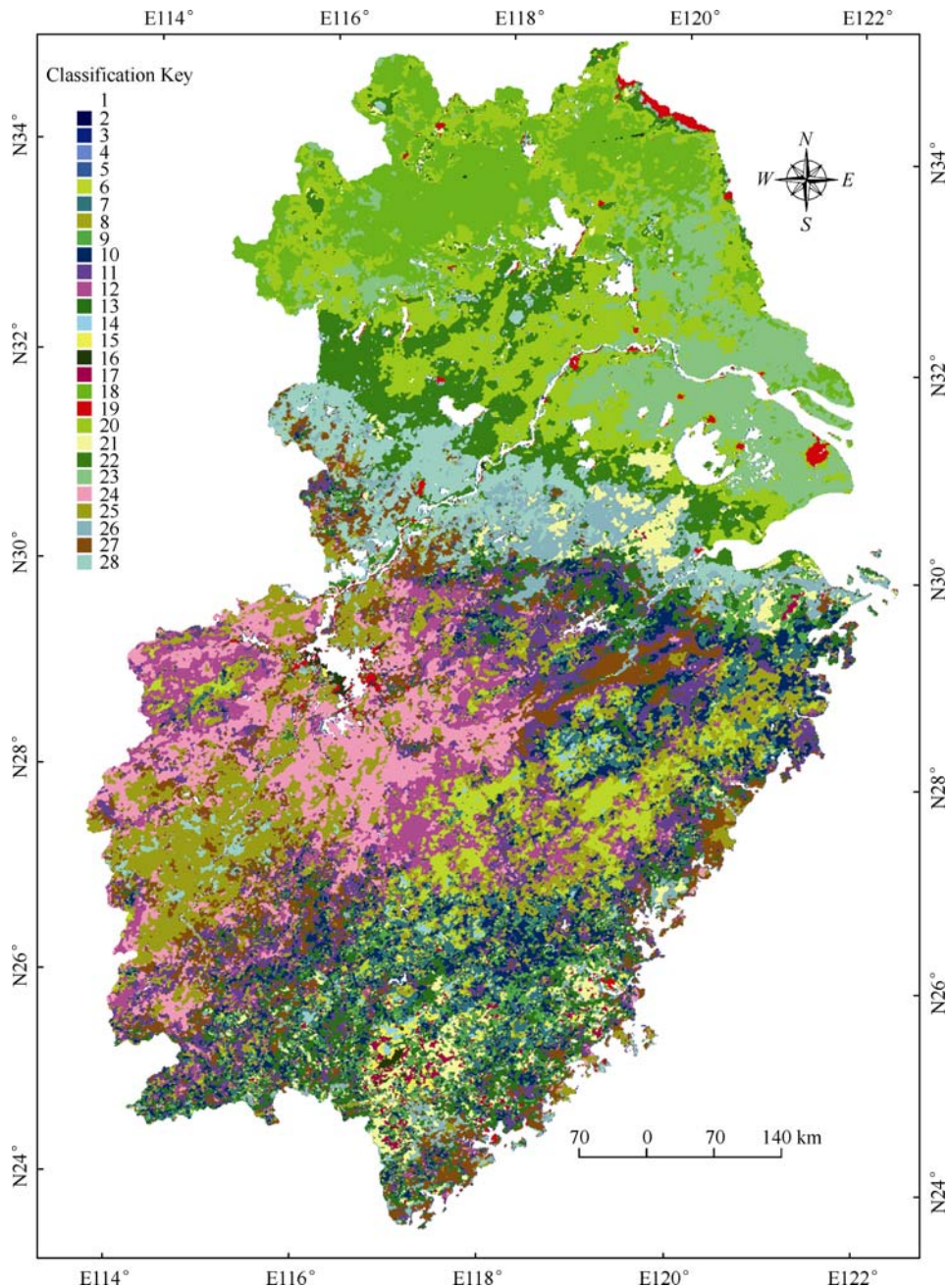
ters of vegetation in East China, the clusters were checked and testified reciprocally with field investigation data and existing vegetation maps of five provinces and Shanghai City (Editorial Board of Vegetation of Anhui Province, 1983; Editorial Board of The Forest of Jiangxi Province, 1986; Lin, 1990; Editorial Board of the Forest of Zhejiang Province, 1993; Song, 1999). We found that the classification scheme of 28 clusters was more suitable for the real-world vegetation conditions after careful checking and analysis. Then each cluster was identified into the corresponding vegetation type based on the field data and existing vegetation maps. They were: (1) water; (2) aquatic vegetation; (3) aquatic or swamp vegetation; (4)swamp or beach vegetation I; (5) swamp or beach vegetation II; (6) evergreen broad-leaved forest type I; (7) evergreen broad-leaved forest types II; (8) coniferous forest I (*Cunninghamia lanceolata*); (9) needle-leaved forest type I (*Pinus massoniana*); (10) needle-leaved forest type II (*Pinus*-dominated); (11) needle-leaved broad-leaved mixed forest type; (12) evergreen orchards or evergreen shrub types; (13) coniferous forest type II; (14) low shrub grass type I; (15) low shrub-grass type II; (16) low shrub-grass type III; (17) low shrub-grass type IV; (18) 1-year two-ripe crop in dry farmland (wheat+corn); (19) urban area or bare sand beach; (20) 1-year two- or 2-year three-ripe crop (rice+wheat/rape); (21) bamboo forest type; (22) 1-year two- or three-ripe crop (rice + rape); (23) 1-year two- or three-ripe crop (rice dominated); (24) 1-year two-ripe crop(rice + rice); (25) 1-year two- or three-crop in irrigated land (rice); (26) deciduous shrub; (27) 1-year two-ripe crop (rice-dominated); (28) montane brushwood, respectively.

Among the 28 clusters, 26 clusters were vegetation land-cover types except water body and urban land-cover type. The 26 vegetation land-cover types were then reclassified into six vegetation types, such as evergreen broad-leaved forest type, needle-leaved forest type (in which the needle-leaved broad-leaved mixed forest type was merged), shrub-grass type, bamboo forest type, aquatic vegetation type, and agricultural vegetation type, respectively, in terms of the taxonomic systems in Vegetation of China (Wu, 1980).

The results demonstrated that the spatial distribution of classified vegetation types was rather agreed well with that of the real-world zonal vegetation whether in nature or agriculture in East China (Plate 1). Their spatial array, from north to south was of dry farming vegetation belt (zone), dry-land/irrigated agricultural vegetation belt (zone), two-crop rotation (rice-dominated) agricultural vegetation belt (zone), deciduous evergreen broad-leaved mixed forest belt, typical evergreen broad-leaved forest belt, and two/three-crops rotation (rice dominated) agricultural vegetation respectively. The boundary of each vegetation type was spatially clearly delimited.

3.2 Classification accuracy assessment

To test our classification accuracy, the digitalized vegetation



(1): water; (2): aquatic vegetation; (3): aquatic or swamp vegetation; (4): swamp or beach vegetation I; (5): swamp or beach vegetation II; (6): evergreen broad-leaved forest type I; (7): evergreen broad-leaved forest types II; (8): coniferous forest I(*Cunninghamia lanceolata*); (9): needle-leaved forest type I(*Pinus massoniana*); (10): needle-leaved forest type II(*Pinus* dominated); (11): needle-leaved broad-leaved mixed forest type; (12): evergreen orchards or evergreen shrub types; (13): coniferous forest type II; (14): low shrub grass type I; (15): low shrub grass type II; (16): low shrub grass type III; (17): low shrub grass type IV; (18): one year two ripe crop in dry farmland (wheat+corn); (19): urban area or bare sand beach; (20): one year two or two year three ripe crop(rice+wheat/rape); (21): bamboo forest type; (22): one year two or three ripe crop(rice + rape); (23): one year two or three ripe crop(rice dominated); (24): one year two ripe crop(rice + rice); (25):one year two or three crop in irrigated land(rice); (26): deciduous shrub; (27):one year two ripe crop(rice dominant); (28): montane brushwood.

Plate 1 Map of vegetation classification in East China

types from the Atlas in 1:1 000 000 scale were used as references. Each sheet of maps was scanned, geocoded, mosaicked and digitalized supported by Geographic Information Systems (GIS), and then the geodatabase of the vegetation types from the Atlas was established for final use. The digitalized vegetation types were then overlaid on the clas-

sified vegetation types to test the accuracy. There were totally 78 vegetation sub-types in East China in the Atlas. They were then reclassified into eight vegetation types to facilitate the overlay spatial analysis.

Our accuracy assessment was divided into two aspects. One was the type accuracy assessment, which tested the

types and spatial location. The other was the area accuracy evaluation which focused on the area of each classified vegetation type compared with the digitalized one.

The cartographic vegetation data used for compilation of the Atlas were mainly investigated from 1950 to 1987. That was to say that there was a time-lag of 8 to 45 years between the cartographic data and the remotely-sensed data we used. Moreover, there was no newest data to update the spatial-temporal vegetation dynamic by the end of 2000. We could not acquire the simultaneous vegetation data to check our classified results. To do so, we compared and checked the map data with our results in the premise that if the overlapped area between the validation vegetation patch and our classified vegetation patch was more than 1 km², we would then take the classified type and its geographic location were right. Before overlaying, the classified vegetation map was processed with a 3 × 3 filtering for the cartography of vegetation mapping, then the numbers of the overlapped vegetation patches, therefore, were considered to be the correctly classified ones, and used to evaluate the accuracy (Table 2). As for area accuracy, the comparisons were conducted between the reclassified digitalized types from the Atlas and our corresponding identified types (Table 3).

Table 2 Type accuracy assessment of the classified vegetation types in East China

	NLF*	EBLF	BF	SHG	AV	CV	DBF	EDMF
Patches identified (3×3 filtered)	1654	727	553	1092	2143	1425	–	–
Patches digitalized	3388	765	453	1251	69	2904	109	51
Patches overlapped	2684	522	130	1142	48	2786	–	–
Accuracy /%	79.2	68.2	28.7	91.3	69.6	95.9		

*: Needle-leaved broad-leaved mixed forest was merged into needle-leaved forest; NLF: needle-leaved forest; EBLF: evergreen broadleaved forest; BF: bamboo forest, SHG: shrub-grass; AV: aquatic vegetation; CV: cultivated vegetation; DBF: deciduous broadleaved forest; EDMF: evergreen broad-leaved deciduous broadleaved mixed forest

Table 3 Area accuracy assessment of the classified vegetation types in East China

Identified vegetation type	Area of identified types /km ²	Digitalized vegetation types from the Atlas	Area of digitalized types /km ²	Errors of area /km ²	Area accuracy /%
NLF	150292.0	NLF	163184.5	–12892.5	92.1
EBLF	35427.0	EBLF	26010.4	9417.0	63.8
BF	16243.0	BF	16823.5	–580.0	96.5
SHG	85462.0	SHG	89067.0	–3605.0	95.9
AV	5555.0	AV	1713.0	3842.0	324.3
CV	286328.0	CV	316212.1	–29884.0	90.5
Water*	55005.0	Water*	22034.4	32971.0	249.6
Urban/bare soil*	4288.0				
		EDMF	1108.9		
		DBF	4563.8		
Total	638600.0		639000.0	–400.0	99.9

*: Non-vegetation types

There were rather high accuracy for the agricultural vegetation, shrub-grass vegetation and needle-leaved forest identification (Table 2, Table 3). Their accuracy of type and geographic location reached 95.9%, 91.3% and 79.2% respectively, while their area accuracy reached 90.5%, 95.9% and 92.1% respectively. But the accuracy of type for evergreen broadleaved forest was only 68.2%, whereas the area accuracy was 63.8%, but reached 91.3% after 3 × 3 filtering. There were rather accuracy variation between accuracy of type and area for the bamboo forest and aquatic vegetation. The accuracy of type and geographic location for bamboo forest was only to 28.7%, but its area accuracy reached 96.5%. This was mainly because the bamboo forest distributed in Wuyi Mountains in the western part of Fujian province, and in the mountains, such as Jiuling Mt., Wugong Mt., Luoxiao Mt., etc., in the eastern and western parts of Jiangxi province, could not be identified in the remote sensing imagery. The accuracy of aquatic vegetation types also reached 69.6%, but the area of identified was as large 3.2 times as that of digitalized. So, the area accuracy was unreliable. This was probably due to two reasons: (1) the area identified from remotely sensed imagery was as large 2.5 times as that of digitalized from the Atlas; (2) the remotely-sensed data we used spanning 7 months (from February to August) covering the period from low-water to high-water of the rivers and lakes based on the regional climatic rainfall season. This maybe induced the area variations between the water and the intertidal vegetation.

There were two vegetation types, subtropical deciduous-evergreen broad-leaved mixed forest and subtropical deciduous forest in the Atlas, but they could not be recognized and identified in our study. There were two possible explanations. The forest canopy was composed of mixed forest and/or deciduous forest, but the underlayer shrub was evergreen, so the spectral reflectance of the underlayer was mixed with forest canopy; The other was related to the imagery acquisition time, i.e., identifying the deciduous forest should need full 1-year time-series NDVI data sets theoretically.

4 Discussion

The time-series NDVI data can be used for vegetation classification because it is sensitive to vegetation greenness and dynamics, especially to plant phenological dynamics. In this study, we used NDVI time-series data for vegetation classification in East China. The identification of the six vegetation types with rather high accuracy demonstrates that it is feasible to use time-series NDVI data to identify the vegetation types in subtropical evergreen broadleaved forest zone in East China. Our result is consistent with the earlier works that used the derived NOAA-AVHRR NDVI data (DeFries et al., 1994; Eidenshink et al., 1994; Sellers et al., 1994; Townshend, 1994; Townshend et al., 1994; Cihlar et al., 1996). In the International Geosphere–Biosphere Program's land-cover legend, there are ten types concerning vegetation

as evergreen needle-leaved forest, evergreen broad-leaved forest, deciduous needle-leaved forest, deciduous broad-leaved forest, mixed forest, closed shrublands, open shrublands, woody savannas, savannas, and grasslands, respectively (Belward, 1996). In USGS Land-Use/Land-Cover System Legend (Modified Level 2), there are also nine vegetation types as evergreen needle-leaved forest, evergreen broad-leaved forest, deciduous needle-leaved forest, deciduous broadleaf forest, mixed forest, shrubland, mixed shrubland/grassland, savanna and grassland, respectively (USGS, 2004). In the land-cover types for Simple Biosphere 2 Model, there are 11 land-cover types concerning vegetation as evergreen broad-leaved trees, broad-leaved deciduous trees, evergreen needle-leaved trees, deciduous needle-leaved trees, deciduous and evergreen trees, ground cover with trees and shrubs, ground cover only, broad-leaved shrubs with perennial ground cover, broadleaf shrubs with bare soil, groundcover with dwarf trees and shrubs, Agriculture or C3 Grassland, (Sellers et al., 1996). All these classification regimes are widely used as datasets for global climate change research, vegetation productivity estimation in large scale, and so on. So, our classification results can be usable to such studies as well in East China.

It is very difficult to identify the sub-pixel vegetation types with coarse resolution remotely sensed data, such as NOAA-AVHRR data, because of the complex topography, diverse species components of vegetation and the higher landscape heterogeneity in East China. So, higher spatial resolution remote sensing data, such as Landsat-TM/ETM+ and SPOT, should be needed to achieve that goal. But, if the vegetation classification reaches community level, fine spatial resolution data which can identify the forest canopy structure and even species composition, i.e. 1 and/or 4 m IKONOS data, 0.61 and/or 2.44 m Quickbird data, should be considered.

Accuracy assessment of land-cover, vegetation/forest classification is critical and challenging to remote sensing community. Accuracy assessment is generally done in three spatial scales: (1) field-based point survey data (micro-scale); (2) fine resolution space-borne remotely sensed data (e.g. Landsat TM, SPOT and IKONOS) and/or aerial photos (medium scale), and (3) forest inventory data across large spatial domains (macro-scale) (Xiao et al., 2002). Because of the data availability of finer resolution land-cover derived from Landsat TM/ETM+, and scarce field survey data, we turn to use digitalized vegetation map data from Vegetation Atlas of China in 1,000,000 scale to validate our results. In the Vegetation Atlas of China, there are totally 78 forest sub-types as dominant species level, but our types only reach 26. So the digitalized and the classified vegetation types are all reclassified to facilitate comparison and validation. Furthermore, there is nearly a time-lag of 40 years between the no updated Vegetation Atlas of China and our remotely sensed data, and the accuracy assessment validated with the Atlas map data have induced some uncertainty inevitably. We will employ finer resolution data such as Landsat-TM/ETM+ or SPOT data to improve our classification accuracy in further study.

5 Conclusions

In our study, we concluded that the NOAA-AVHRR time-series maximum NDVI composite imagery data can be used to identify the vegetation types in subtropical evergreen broad-leaved forest zone in East China. Twenty six clusters of vegetation types are identified and then merged into six vegetation types in higher taxonomy level. The geographic distributions of the six vegetation types are coincided with that of the real-world zonal vegetation in this region. Moreover, the higher classification accuracy and reliability of the six vegetation types in type, geographic location, and area, compared with the Vegetation Atlas of China, suggest that our classification types and vegetation map can be used to the research field such as global climate change, vegetation productivity estimation, and so on.

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