Temporal-spatial characteristics of vegetation cover and desertification of China by using remote sensing data*

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Abstract Based on the NOAA advanced very high resolution radiometer (NOAA-AVHRR) remote sensing data of 1982～1999, the normalized difference vegetation index (NDVI) reflecting the surface vegetation cover has been obtained. Using the empirical orthogonal function analysis, the temporal-spatial eigenvectors of NDVI are given, and the characteristics of the spatial distribution of vegetation cover and its temporal variation together with the desertification of China are analyzed. It is found that the surface vegetation cover has seriously deteriorated in most part of China since 1995, along with the intensified desertification. All these are mainly caused by human activities although the climate change is responsible for the damage of surface vegetation cover to some extent.

Keywords: remote sensing, surface vegetation cover, empirical orthogonal function, normalized difference vegetation index.

Vegetation cover occupies about 50% of land surface, it is easily affected by the environment and human activities. With the change of vegetation cover and land surface characteristics, the energy fluxes balance between land surface and atmosphere will be readjusted, which in turn will greatly affect the national economic development[1,2]. In the process of energy and mass exchange with the atmosphere, vegetation features themselves are also changed, and then further affect the exchanges of energy and mass fluxes between vegetation and environment[3].

With the advance of remote sensing technology, many achievements in the retrieval of surface vegetation coverage and its variation have been obtained using the remote sensing data[4～7]. As an important parameter for the study of surface vegetation cover, the normalized difference vegetation index (NDVI) is retrieved through the difference of reflectivity between channel 1 and channel 2 in the field of remote sensing to obtain the information about the land surface cover and its dynamic variation. Generally speaking, NDVI indicates not only the influence of climate variation on the change of surface vegetation cover, but also the influence of human activities. Due to its vast territory that spans several climatic zones from north to south, China has great diversity of the land surface vegetation types have great diversity. With the economic development of the last 20 years, natural environment and land surface vegetation have been greatly destroyed in many areas, and desertification has become much more intensified. In order to analyze the distribution of vegetation cover and its variation in China, the NOAA-AVHRR remote sensing data with 8 km × 8 km resolution obtained during 1982～1999 are used in this study, and the impact of climate variation and human activities on the surface vegetation cover is investigated by means of empirical orthogonal function (EOF) analysis for the monthly maximum NDVI data.

1 Characteristics of surface vegetation cover

Through the comparison of monthly maximum NDVI data from 1982 to 1999 it is found that the land is mostly covered by vegetation in July in China, and the habit of cultivation is generally unchanged in different regions. So the maximum NDVI of July is analyzed by means of EOF method, and a total of 17 eigenvectors and their temporal weighting coefficients are obtained. Every eigenvector reflects the distribution of primary and secondary land surface information, and the temporal weighting coefficient reflects the variability of the eigenvector against time. Table 1 shows 13 eigenvectors, variances and the accumulated variance. We can find that the first eigenvector

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accounts for 36.7% of total variance, which is much more larger than the percentage of variance explained by other eigenvectors. And this may indicate that the EOF analysis can correctly describe the temporal and spatial variations of NDVI.

Table 1. The percentage of variance explained by the eigenvectors in EOF expansion of maximum NDVI field in July (unit: %)

Serial number	1	2	3	4	5	6	7	8	9	10	11	12	13
Eigenvectors	6.31	1.69	1.21	1.01	0.94	0.81	0.75	0.70	0.69	0.63	0.54	0.44	0.40
Variance/%	36.7	9.90	7.00	5.80	5.40	4.70	4.30	4.10	4.00	3.60	3.10	2.50	2.30
Accumulated variance/%	36.7	46.6	53.6	59.4	64.8	69.5	73.8	77.9	81.9	85.5	88.6	91.1	93.4

1.1 First eigenvector and temporal weighting coefficient

Fig. 1 shows the distribution of first eigenvectors, we can find that most of them are positive, and

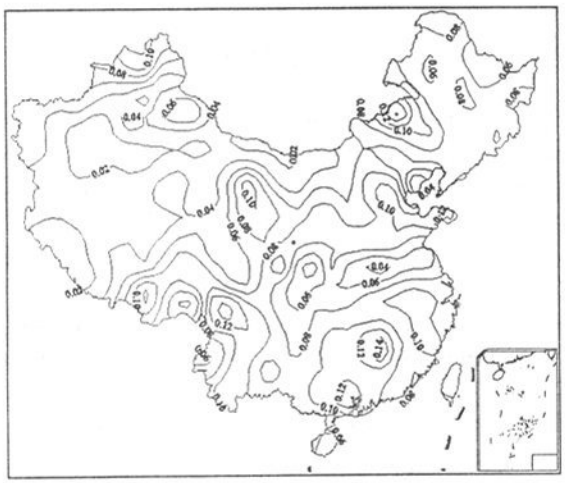

Fig. 1. Distribution of the first NDVI eigenvectors.

the corresponding temporal weighting coefficients are also generally positive from 1984 to 1994 (Fig. 2), which indicates that land of the regions was densely vegetation-covered from 1984 to 1994. From 1995, the temporal weighting coefficients become negative (Fig. 2), suggesting that the region with high values becomes poor vegetation-covered from that time, either by desertification or by intensified damage of environment in the area.

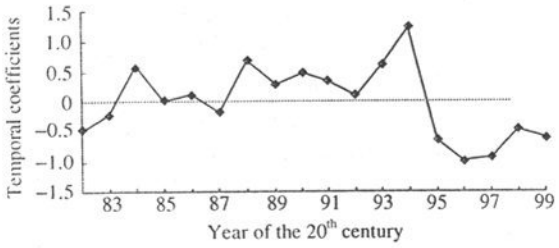

Fig. 2. Temporal weighting coefficients of the first NDVI eigenvectors.

1.2 Regions with deteriorated vegetation cover

From Fig. 1 we can find several relatively large regions with distinctly high value of first eigenvector. In the west, including Inner Mongolia, Ningxia, Gansu, Shanxi, Shaanxi, Xinjiang and Qinghai, the vegetation cover has been replaced by desert, and the expanding of desert and semi-desert areas leads to the deteriorating of vegetation cover over these regions. Especially over Inner Mongolia, for example, the Great Bend of the Yellow River area had abundant water system on land surface, and dense forest, lush cropland and other vegetations occupied most of the region in the 1980s, but the vegetation cover started declining from 1995, which proceeded fast. This happened in Hulunbeier as well, where the vegetation-covered land reduced rapidly. In the east and north of China, although the spatial scale is relatively small, especially for Henan, north China, the Yangtze River delta, Sichuan, northeast China, central China, south China, the Yun-Gui plateau and some coastlands, the degradation of vegetation cover is becoming more and more serious. At the beginning of the 1980s, there were higher degree of vegetation coverage and less bare soil over the above regions; however, large non-vegetation regions with bare soil appeared from the last decade.

In order to assess the degree of degradation of land surface in western China, the samples of NDVI are selected respectively from desert and sparse-vegetation-covered regions according to the GIS dataset of the early 1980s and mid 1990s. The cluster analysis of the monthly maximum NDVI between 1982 and 1999 shows that NDVI is less than 0.06 in the desertification regions (occupies 97.9% of desertification sample) and lies between 0.06 and 0.16 in the region with sparse vegetation cover (occupies 97.9% of few vegetation cover sample). So we consider the land surface as desert when its NDVI is less than 0.06, and as covered by little vegetation but tending to de-

sertification when NDVI lies between 0.06 and 0.16. According to the above criterion, the area with desert and desertification trend is calculated and shown in Fig. 3, and we can find that it varies obviously with time; furthermore, the change of desert area is out of phase as compared with the area change of regions with sparse vegetation covers (Fig. 3).

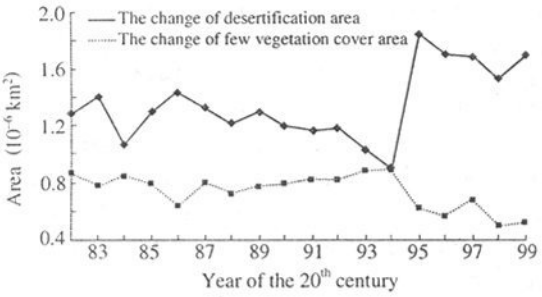

Fig. 3. The annual change of desertification area.

This indicates that the increased desert area is mainly caused by the soil degradation of sparse vegetation cover region. From 1982 to 1994, the tendency of desertification weakened and the area of sparse vegetation cover was increasing. The difference between the mean NDVI during 1995～1999 and 1982～1994 shows directly that the vegetation cover reduced significantly from 1995 (Fig. 4). The most serious regions (with NDVI less than 0.1) are in the eastern Inner Mongolia, north China, central China, south China, Gansu, Ningxia, northern of Xinjiang, Shanxi, Henan, Sichuan and the YunGui plateau. This result agrees quite well with the analysis of the first eigenvector and temporal weighting coefficients, and the degradation of vegetation can also be clearly observed from the satellite image (Plate IA).

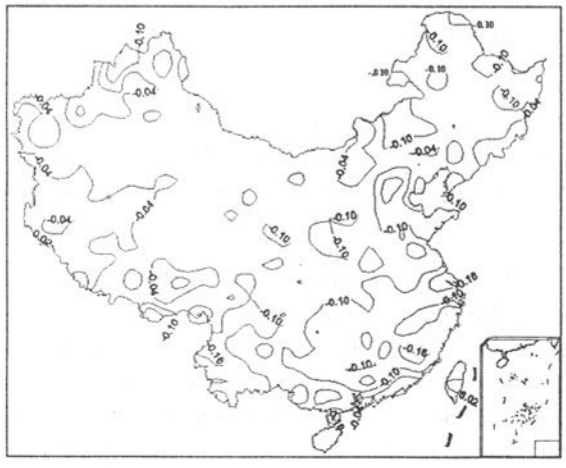

Fig. 4. Difference in average NDVI between 1995～1999 and 1982～1994.

2 Factors influencing vegetation cover

It is the regional climate and geography that determine the distribution of surface vegetation types and their upgrowth, and soil texture and precipitation are two more important factors. However, soil texture depends strongly on the local climate condition, and its change periodicity is very slow, hence precipitation is the most important one in all natural factors influencing the surface vegetation cover. In addition, in recent years, human activity is becoming an important factor[8～10].

2.1 Regions influenced remarkably by precipitation

It is well known that precipitation provides necessary water for the growth of vegetation. In regions with low soil moisture, there exists high positive correlation between NDVI and precipitation. However, this kind of correlation becomes inconspicuous as rainfall is plenty enough and soil becomes wetter. Fig. 5 shows the distribution of correlation coefficient between NDVI and precipitation. Because of the lag response of vegetation to rainfall, the precipitation data used here is the sum of rainfall in May, June and July of the years 1982～1999.

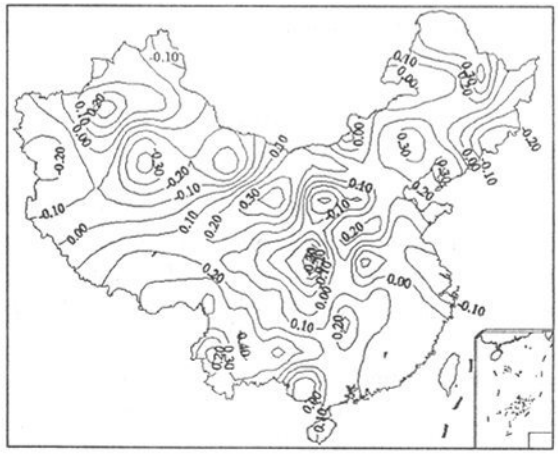

Fig. 5. Correlation between NDVI and total precipitation of May, Jun, July of year 1982～1999.

From Fig. 5 we can find that regions with high correlation coefficient are generally located to the north of the Yellow River, including north part of Gansu, some part of Ningxia, north part of Inner Mongolia and western Xinjiang. The reason for this kind of distribution in these regions is that the precipitation is quite small, so the climate is quite dry and the water supply for vegetation growth comes mainly from natural rainfall. For the desert and grassland in

northern China, vegetation is very sensitive to rainfall, a light rainfall can obviously change the land cover feature. In regions south of the Huaihe River where the rainfall is plenty enough, such as the middle reaches of the Yangtze River and its neighborhood, southeast part of Yunnan and Tibet, the high correlation coefficient can also be found in certain small regions. Because land cover types are dominated by triple annually and needle-leaf evergreen forest, broadleaf evergreen forest and evergreen scrub are widely distributed, these trees are more sensitive to rainfall due to the relative high latent heat flux.

Generally, the correlation between NDVI and precipitation is not significant in the most part of China. The EOF analysis for the total precipitation of May, June and July of 1982～1999 shows that the variation of rainfall is quite little to the north of the Huaihe River, and quite remarkable to the south of Huaihe River where the total precipitation is abundant. These indicate that the variation of precipitation is not the main cause leading to the decrease of vegetation cover in the most part of China; instead, the influence of human activities becomes more and more important. The negative correlations (<0.3) in Xinjiang, north China and Sichuan further confirm the influence of human activities on land surface vegetation cover.

2.2 Regions influenced remarkably by human activities

The effects of human activities on environment depend on the density of population, economic activity and lifestyle of human beings. In western China, population density is generally less than 20 persons per square kilometer (Plate IB), and economic activities depend mainly on natural resources. When the climate changed little, human destruction and immoderate animal husbandry are the primary foctors making vegetation cover decrease in the north of Guansu, midland and eastern Inner Mongolia after 1995. In eastern China, population density is high and economy develops rapidly, especially in the Yangtze River delta, central China, south China and coastland, the population density is generally more than 200 persons per square kilometer, and the economic development has been very fast in recent years. As a result, some negative effects are brought in on the ecosystem and environments, e.g. the initial ecosystem is destroyed and larger range of bare soil exposed in these regions.

In northern China, the population is the densest. Besides human activity, the continual reduction in natural resources is also an important factor that makes vegetation cover decrease remarkably. Investigation results showed that, due to the poor management and continuous aridity in the Yellow River region since 1986, both the duration and range of aridity were also increasing. Take Lijin Hydrographic Station as an example, the days of dry season were 38 days in 1992, 60 in 1994, 74 in 1994, 122 in 1995, 133 in 1996 and 226 in 1997. Hence, the lower reaches of the Yellow River has become extremely dry since 1995. The ecosystem has become imbalanced and soil has deteriorated in the Yellow River valley. At the same time, salina of coastland is also increasing[11,12].

Based on the distribution of population density, we can find that the vegetation cover generally decreases either in the eastern or in the western part of China where the population density is more than 20～200 persons per square kilometer, and this may be closely related with the sharply increasing population and the continually expanding cities.

3 Conclusions

(i) The change of surface vegetation cover was generally quite mild from 1982 to 1994, the coverage of surface vegetation tended to be improved, especially in western China, the vegetation cover decreased only in a few individual years.

(ii) Surface vegetation cover deteriorated remarkably in the most part of China since 1995, and desertification is becoming more and more serious in western China. All these are caused mainly by the human activities and the resultant degeneration of natural resources.

(iii) Generally, precipitation is not the main factor causing the degradation of vegetation cover in China, except in some sparsely populated arid and semiarid regions.

(iv) Human activities are probably the leading cause for land cover change, and there are two distinctions in the regions with deteriorated surface vegetation cover: one is that economy is under-developed in these regions, and its development depends mostly on natural resources; the other is that economy develops rapidly, and human activities have changed the initial surface vegetation type.

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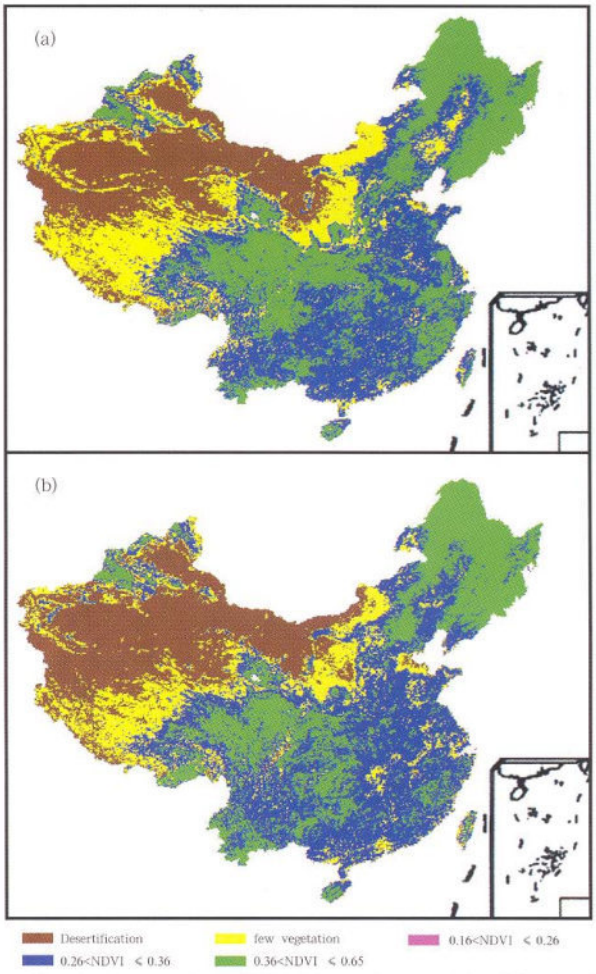

Plate IA. A comparison of NDVI change between July, 1982 (a) and July, 1999 (b).

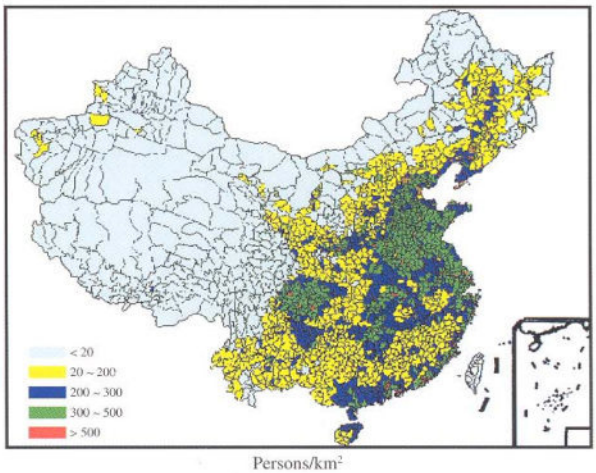

Plate IB. Distribution of the density of population in China.