

Fourier Analysis of Multitemporal Vegetation Index data

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Abstract

Fourier analysis is applied to multitemporal global normalized vegetation index (NVI) data for extracting the useful parameters for monitoring environment change. It is found that the third order of power spectrum can be used for monitoring agriculture areas with two crops in a year. And also, the phase of the first order is used for finding the peak of the monthly NVI data and can be used for monitoring the variation of the season. We show the usefulness of the power spectrum maps of each order and the phase map of the first order for monitoring the distribution change of the environment condition.

Key Words: Fourier Analysis, NVI data, monitoring, Image processing

1. Introduction

Environmental change, for example, decreasing of tropical rain forest and increasing of desert can be monitored as the distribution change of vegetation. Many technical reports of monitoring vegetation have been written recently.¹⁾⁻⁶⁾ In these reports, maps of the monthly data or integrated value of NVI data over one year are used. But it is difficult to interpret the detail of variation of NVI data over a year. Recently, the principal component analysis has been applied to multitemporal NVI data for extracting the useful parameters for monitoring the environment change⁷⁾. But it is not so easy to understand the physical meaning of the variation of multitemporal NVI data using the extracted parameters. Because the same variations in the north hemisphere and the south hemisphere can not be identified as the same phenomenon. So, Fourier analysis is proposed here for extracting the useful parameters from the multitemporal NVI data. Fourier analysis is well known as the method that extracts the amplitudes and the phases of basic waves constructing an original wave. It is expected to interpret the detail of variation of multitemporal NVI data easily from the amplitudes and the phases of one or two basic waves. For example, it is expected that the phase is corresponding to the season. The phase can be used for monitoring the variation of season. In this report, Fourier analysis method is mentioned briefly, and the results that multitemporal NVI data is analyzed by Fourier analysis is shown.

2. Method

Here, the construction method of monthly NVI data and Fourier Analysis method are explained for extracting the useful representative parameters.

2-1. Monthly NVI data

Since April of 1982, weekly global normalized vegetation index (NVI) data using channel 1 and 2 of AVHRR have been constructed by NOAA/NESDIS of USA. The original images of the northern hemisphere and the southern hemisphere consist of 1024x1024 pixels and these images are polar stereographic projection images. The pixel interval is about 15km on the equator, and about 30 km on the poles. Justice et al. have mentioned that these data with coarse spatial resolution and high temporal frequency are suitable for vegetation mapping and monitoring at global scales. But the monthly data is considered to be enough and be better than the weekly data for analyzing the year change of vegetation. So, the monthly NVI data is made by selecting maximum value in pixels of weekly NVI data in each month. And to keep the stability of the data, the final monthly NVI data is obtained by averaging same monthly NVI data from April of 1982 to March of 1985. In the monthly NVI data, the data of the seas and lakes are changed to be zero by the mask made by using the information of the coast lines. These data are analyzed by Fourier analysis.

2-2 Fourier Analysis

Fourier analysis is used to obtain the amplitude and the phase of each basic waves included in an original wave. The monthly NVI data of each area is considered to be waves, because these data have nearly same value in same month of different years. The amplitude and the phase of the monthly NVI data $f(t)$ are obtained by using the next equation.

$$F(u) = f(t) \exp(-2\pi i u t) dt \quad --(1)$$

Here, u is the frequency.

$F(u)$ is rewritten by the next form.

$$F(u) = R(u) + iI(u) \quad \text{--(2)}$$

$$F(u) = p^{1/2}(u) \exp(i\phi(u)) \quad \text{--(3)}$$

$$p(u) = R^2(u) + I^2(u) \quad \text{--(4)}$$

$$\phi(u) = \tan^{-1}(I(u)/R(u)) \quad \text{--(5)}$$

$R(u)$ and $i(u)$ are the real part and the imaginary part of the $F(u)$ respectively. i is the imaginary unit. $p(u)$ is the power spectrum. $\phi(u)$ is the phase. Here, discrete Fourier transformation is used, because a set of the monthly NVI data consists of 12 discrete data.

The frequency u is given as follows.

$$u = k/12 \quad (k=0,1,2,3..) \quad \text{--(6)}$$

$F(0)$ is the mean of the monthly NVI data. $P(1/12)$ and $\phi(1/12)$ are the power spectrum and the phase of one year period. They are called the first order power spectrum and the first order phase respectively. $P(1/12)$ is considered as the parameter for monitoring the temperate zone. $\phi(1/12)$ represents the peak position of the monthly change and is considered as the parameter of summer in the temperate zone to frigid zone or wet season in the tropical zone. $P(2/12)$ is the power spectrum of the half year period and called second order power spectrum. $P(2/12)$ can be large in the frigid zone because of the short summer. And also, the agriculture areas with two crops in a year may have large value of $P(2/12)$ because of the rapid change of vegetation index.

3.Result

Fourier spectrum in each representative area, the maps of the power spectrum and the map of the phase of the first order are shown as the results.

3-1.NVI data and it's Fourier spectra.

7 examples of monthly NVI data and it's Fourier spectrum are shown from Fig.1 to Fig.7. Fig.1(a) shows the monthly NVI data of the temperate zone. Fig.1(b) shows the Fourier spectrum of (a).

In this figure, horizontal and vertical axis are the order of spectrum and logarithm of power spectrum respectively. The characteristic of this spectrum is that the values of the first and second order power spectrum are nearly same and is bigger than the value of the third order. This characteristic means that the period of this monthly NVI data is between one year and the half year.

Fig.2(a) shows the monthly NVI data of the agricultural area of middle south zone in the United State of America. And Fig.3(a) shows the monthly NVI data of the agricultural zone in the North of China. In these zone, they have two crops in a year. In these two figures

of the power spectrum, it is found that the value of the power spectrum of the third order is bigger than the value of the second order.

Fig.4(a) and Fig.5(a) show the monthly NVI data of tropical zone in Brazil and India respectively. The power spectrum of two zones resemble each other. The difference is seen in the phase of the monthly NVI data.

Fig.6(a) shows the monthly NVI data of tropical rain zone. Fig.6(b) shows that the value of 0 order is larger than the other order.

Fig.7(a) shows the desert zone of Africa. Fig.7(b) shows that all the value of the power spectrum is low.

From these results, Fourier spectrum of the monthly NVI data is the good parameter for expressing the characteristics of the monthly NVI data. It is expected that the global maps of each order of power spectrum and the map of phase can become the good monitoring maps.

3-2. Maps of power spectrum and phase.

The maps of each order of the power spectrum and the map of the first order phase are constructed by analyzing the monthly NVI data of all area. These maps in Mercator projection are shown in Fig.8 to Fig.12.

Fig.8 is the map of 0 order of the power spectrum that is the mean value of the monthly NVI data. The area with under 0.05 of the mean value of NVI data is determined as the no vegetation area. And these areas can be seen in Sahara desert of Africa, Arabic peninsula, Takuramakan desert of China, and Greenland. These areas are drawn black in the map. The value of the power spectrum is illustrated in white to black. In this map, the area with high value illustrated white is corresponding to the zone of tropical rain forest and agriculture with high harvest. On the other side, the area with low value illustrated dark gray is corresponding to the dry zone and the frozen zone with short term of vegetation.

Fig.9 shows the map of the first order of the power spectrum. The value of the first order of the power spectrum is also illustrated in white to black. The zone with high value illustrated white is seen in middle latitude that is corresponding to East of America and the zone of the north-east of China to Europe. The zone with low value illustrated dark gray is the tropical rain forest zone that has the high value of the 0 order of the power spectrum.

Fig.10 shows the map of the 2nd order of the power spectrum. This map is also made by the same way as the map of the first order. The zone with high value illustrated white is the cold zone where the term of vegetation is nearly 3 months and is covered by snow in

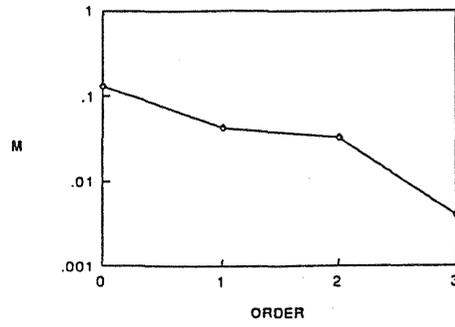
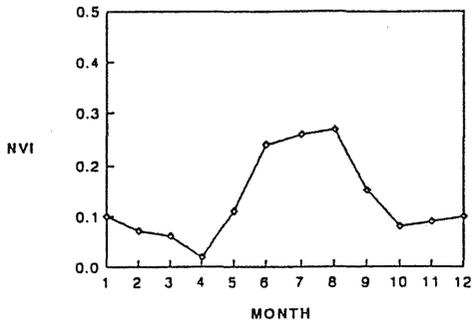


Fig.1(a) Monthly NVI data of the temperate zone.
In (b), horizontal and vertical axis are the order of spectrum and logarithm of power spectrum respectively.

(b) Fourier spectrum of (a).

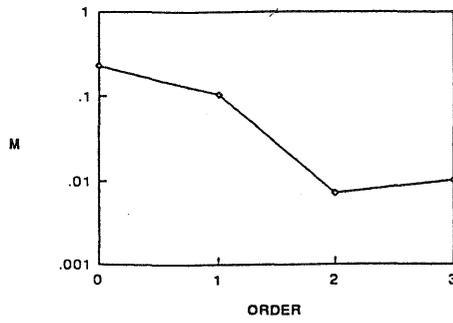
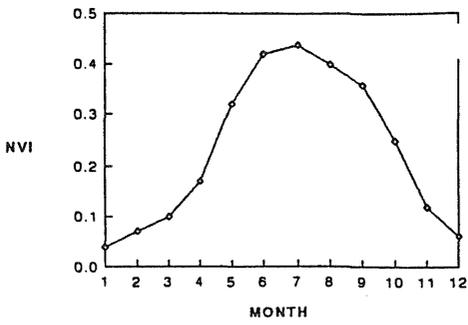


Fig.2(a) Monthly NVI data of the agricultural area of middle south zone in the U.S.A.

(b) Fourier spectrum

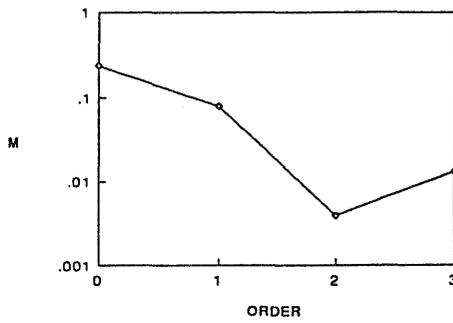
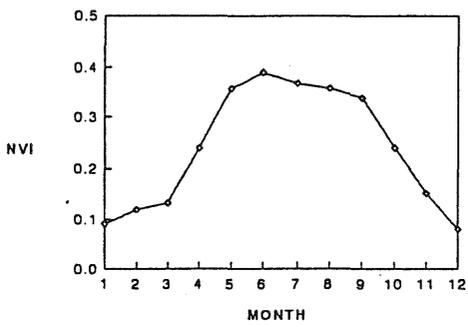


Fig.3(a) Monthly NVI data of the agricultural zone in the North of China.

(b) Fourier spectrum

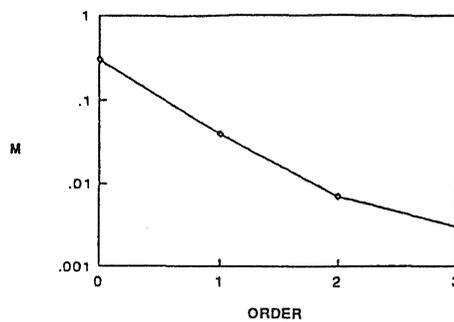
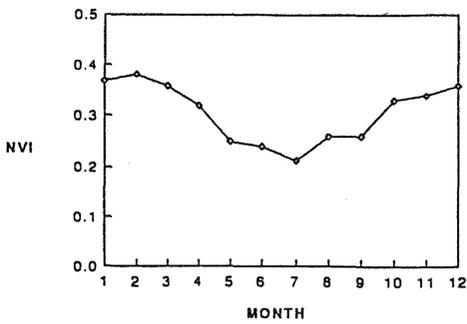


Fig.4(a) Monthly NVI data of tropical zone in Brazil

(b) Fourier spectrum

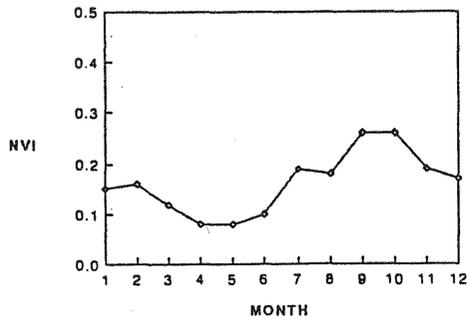
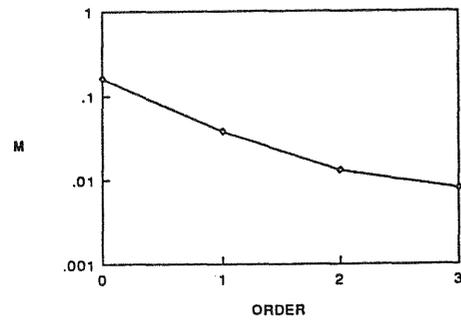


Fig.5(a) Monthly NVI data of tropical zone India



(b) Fourier spectrum

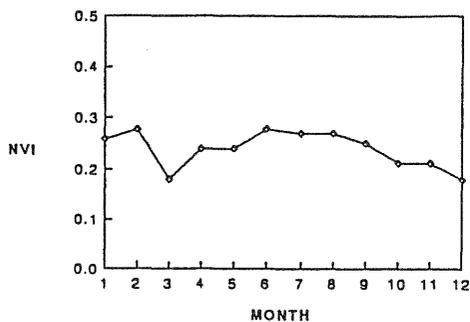
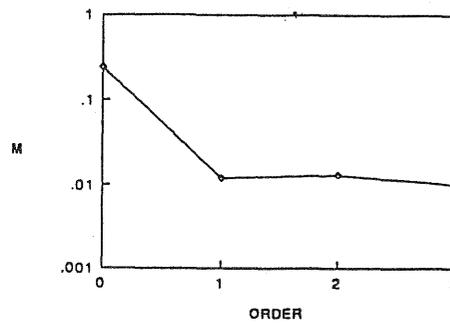


Fig.6(a) Monthly NVI data of tropical rain zone.



(b) Fourier spectrum

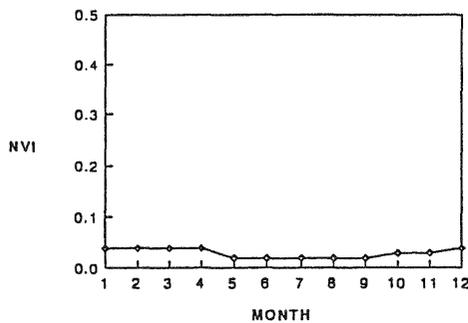
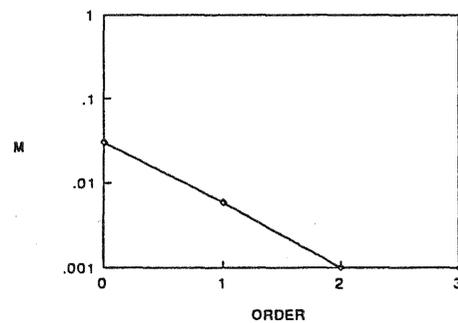


Fig7(a) Monthly NVI data of desert zone of Africa.



(b) Fourier spectrum

half year.

Fig.11 shows the map of the 3rd order of the power spectrum. This map is also made by the same way as the map of the first order. The zones with high value illustrated white are North of China, East of Europe, Ukuraina, East of America, and the tundra. The term of vegetation of the tundra zone is under three months and is covered by ice in almost month. The North of China, Ukuraina, East of America is the place where they have two crops in a year.

Fig.12 shows the map of the phase of first order of the power spectrum. The phase is classified linearly into 4 classes where the peak of the monthly NVI data is located in January to March, April to June, July to September, or October to December. And they are illustrated in white to dark gray. So, almost area of the northern hemisphere is

shown in light gray, and the almost area of the southern hemisphere is in dark gray. But, middle gray is seen in the North of India. This area has the peak of the monthly NVI data in autumn of the northern hemisphere. This season is corresponding to the rainy season in this area. Some areas in Australia don't have the peak of the monthly NVI data in summer of the south hemisphere. It is because each area has different vegetation and climate. The vegetation in the near equator zone of South America is tropical rain forest. So, the phase difference in the south of equator and the north of equator can not be seen. But, the phase difference in the south of equator and the north of equator can be seen in Africa, because savanna in the north of equator and tropical rain forest in the south of equator have peaks of monthly NVI data in the different months.

4. Conclusion

Fourier analysis is applied to multitemporal global normalized vegetation index data for extracting the useful parameters for monitoring the environment change. It is found that the 0 order to the third order of the power spectrum and the phase of the first order is the useful parameters for monitoring the environment change. Especially, the third order of the power spectrum can be used to monitor the two crops areas. And also, the phase of the first order can be used for finding the peak of the NVI data and can be used for monitoring the variation of season. The usefulness of the power spectrum maps of each order and the phase map of the first order is shown here. Maybe, one or two maps are enough to understand the way of change of the monthly NVI data and are enough to monitor the distribution change of the environment condition.

In the next step, usefulness of this method must be examined by using the recent monthly NVI data.

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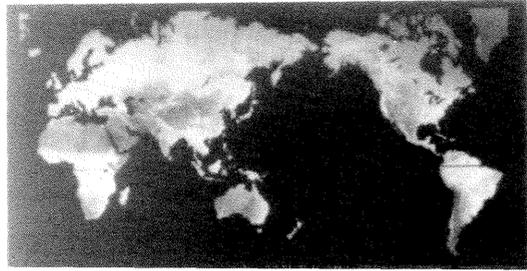


Fig.8 Map of the 0 order of the power spectrum

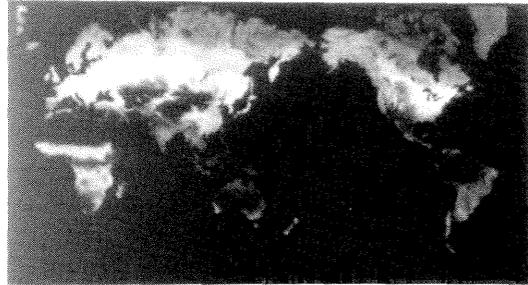


Fig.9 Map of the first order of the power spectrum.

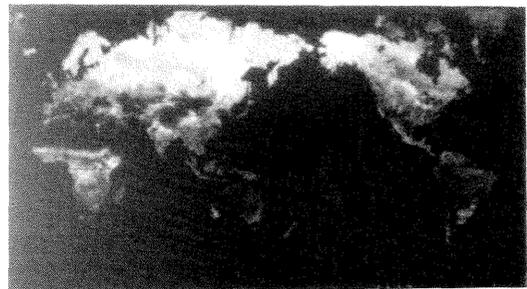


Fig.10 Map of the 2nd order of the power spectrum.

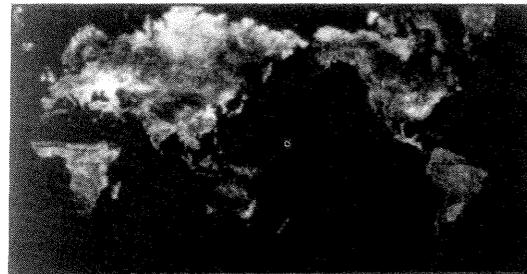


Fig.11 Map of the 3rd order of the power spectrum.

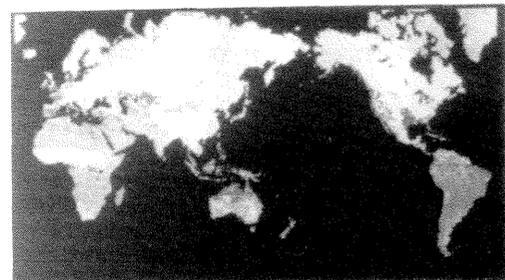


Fig.12 Map of the phase of first order of the power spectrum.