Harmonic Analysis of Time Series NDVI Using NOAA/AVHRR Data

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Abstract: Normalized difference vegetation indices (NDVI) derived from the NOAA AVHRR satellite data were used to estimate vegetation changes in eastern Japan. NDVI data were composited using the maximum value over a month period in order to reduce the effect of cloud contamination. Harmonic analysis of one-year time series NDVI was performed in order to characterize seasonal changes of vegetation. In consequence, the additive image and the amplitude and phase angle images were produced, respectively. Finally, we could classify the characteristics of vegetation into five classes using these harmonic components.

1. Introduction

Forests play very important roles for absorbing and saving the world's greenhouse effect gas CO_2. Vegetation has seasonal cycle and changes from year to year. Therefore, it is necessary to acquire time-series data for a vegetation analysis. Remote sensing is a very effective technology for forest management on a large scale. National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) dataset is a valuable data source for continental and regional land cover and long-term terrestrial monitoring (IGBP 1992, Townshend 1994)[1].

NOAA AVHRR dataset consists of visible band data and near-infrared band data, and

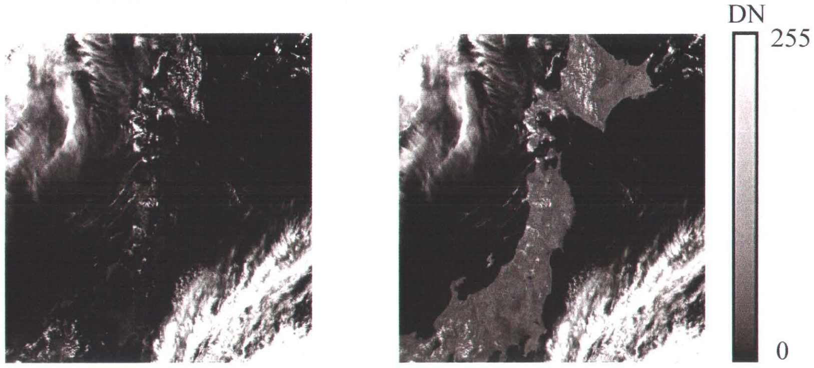


Fig. 9. NOAA AVHRR daily data in eastern Japan (19 September 2002), (a) channel 1 image (visible red band), (b) channel 2 image (near-infrared band).

vegetation index can be calculated from this dataset. Vegetation index is an effective indicator of vegetation activity. Especially, Normalized difference vegetation index (NDVI) based time-series data is used to track global vegetation changes.

Harmonic analysis is useful in that seasonal and intra-seasonal cycles can be highlighted, and offers great promise for analyzing seasonal and inter-annual variation in land surface condition as recorded by NDVI values calculated from time-series remotely sensed data such as the AVHRR[5]. The objectives of this study are to quantify and classify some fundamental characteristics, related to the phenology of vegetation, from time-series of NOAA AVHRR data using harmonic analysis.

2. Data Set Description

In this study, NOAA AVHRR daily data obtained from January 2002 to December 2004 are used as the original data. The spatial resolution of NOAA AVHRR data is 1.1 km. Fig. 9 shows NOAA AVHRR daily data observed in 19 September 2002. Each data covers an area of about 1000 by 1000 km.

3. Methods and Analyses

3.1 Daily NDVI Image

Normalized Difference Vegetation Index (NDVI) gives statistical characteristics for various parameters associated with vegetation growth and type. NDVI images are made from NOAA AVHRR daily data. NDVI is calculated as NDVI = (CH2 – CH1) / (CH2 + CH1), where CH1 and

CH2 represent radiances from channel 1 (0.58-0.68 μm) and channel 2 (0.725-1.10 μm) of the AVHRR, respectively. This is correlated with photosynthetic activities of vegetation and provides an indication of the greenness of vegetation (Sellers 1985)[2].

3.2 Image Registration

In order to match the coordinates of NDVI images, the registration (spatial alignment) between NDVI images is performed. In this process, NDVI images are registered on the vector data, which represents the coastlines, using the ground control points (GCPs)[3]. The geometric correction of NDVI images is performed using the affine transformation. After this process, all NDVI images have same coordinates and can be compared with each other.

3.3 NDVI Composite Image

NDVI value of the surface vegetation cannot be calculated, if clouds cover over the land regions. To interpolate the cloud-covered regions, we create the maximum NDVI composite images proposed by Holben [4] as follows.

In general, NDVI value in a cloud region is smaller than in a vegetation region. In a specific time period, the maximum NDVI values of each pixel are extracted from the daily NDVI images. Therefore the pixel of cloud region, whose NDVI value is smaller than the vegetation region, is reduced, and cloudless NDVI image can be extracted. In this study, the composite period is set up as a one month period, the monthly NDVI composite images are extracted.

3.4 Harmonic Analysis

Harmonic analysis also termed spectral analysis or Fourier analysis is performed to quantify some fundamental characteristics, related to the phenology of vegetation, from time-series of NOAA AVHRR data. Harmonic analysis decomposes a signal into an infinite series of harmonic components. Each of these components is comprised initially of a sine wave and a cosine wave of equal integer frequency.

Let $f(x)$ be a continuous function on $[0,T]$, the Fourier series representation for $f(x)$ is defined as equation (1).

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left(a_n \cos\frac{2\pi nx}{T} + b_n \sin\frac{2\pi nx}{T} \right) \tag{1}$$

Two waves in equation (1) are combined into a single cosine wave, which has characteristic amplitude (size of the wave) and phase angle (offset of the wave).

$$f(x) = A_0 + \sum_{n=1}^{\infty} A_n \cos\left(\frac{2\pi nx}{T} - \theta_n \right) \tag{2}$$

$$A_n = \begin{cases} \sqrt{a_n^2 + b_n^2} & (n = 1,2,...) \\ \frac{a_0}{2} & (n = 0) \end{cases} \tag{3}$$

$$\theta_n = \begin{cases} \arctan\left(\frac{b_n}{a_n} \right) & (n = 1,2,...) \\ 0 & (n = 0) \end{cases} \tag{4}$$

Fourier coefficients a_n and b_n are computed for each term and are then used to calculate the value of the additive term (A_0) and the amplitudes value (A_n) and phase angles value (θ_n) for each of the harmonic components for each pixel in the AVHRR NDVI data set. For a finite data set $\{y(j); j = 1,2,..., N\}$, Fourier coefficient a_n and b_n are defined as follows.

$$a_n = \frac{1}{N-1} \left(y(1) + y(N) + 2\sum_{j=2}^{N-1} y(j) \cos\frac{2\pi n(j-1)}{N-1} \right) \qquad (n \geq 0) \tag{5}$$

$$b_n = \frac{1}{N-1} \left(2\sum_{J=2}^{N-1} y(j) \sin\frac{2\pi n(j-1)}{N-1} \right) \qquad (n \geq 1) \tag{6}$$

In this study, N=12, because the number of the monthly NDVI composite images within one year is twelve. The value of the additive term is the arithmetic mean of NDVI over the time-series (12 periods) and represents the overall greenness of a land-cover type. The amplitude at a one year period measures the maximum variability of the NDVI values from the minimum to the maximum NDVI values. The phase value at a one year period is the time lag between the maximum NDVI and the beginning (January, in our case) of the series (Fig. 10).

3.5 Vegetation Classification based on Harmonic Analysis

Vegetation classification is performed using the harmonic components (2002-2004) obtained by harmonic analysis. The value of the additive term (A_0) and the amplitude values

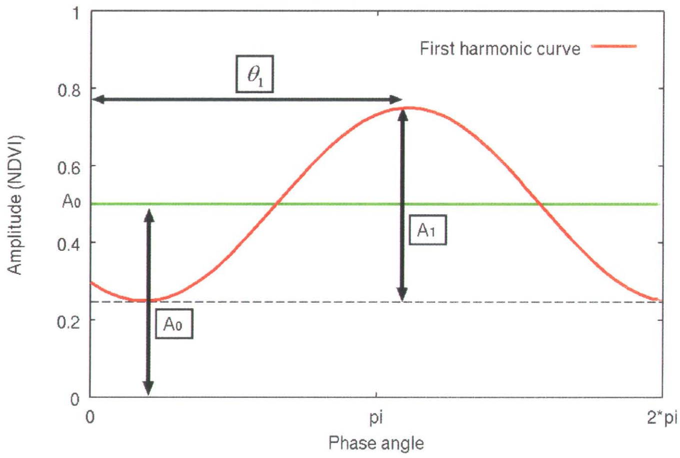


Fig. 10. Schematic representation of the harmonic components for one year; The value of the additive term (A_0), the amplitude value (A_1) and the phase value (θ_1) of the first harmonic term.

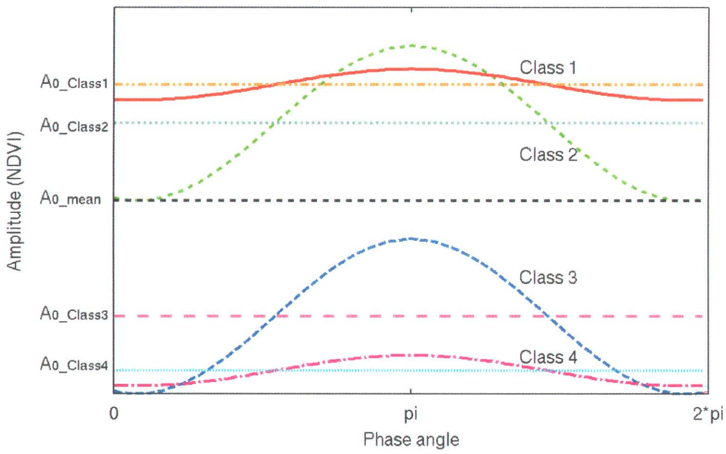


Fig. 11. Four classes used for vegetation classification.

of the first harmonic term (A_1) are used in the classification. In this study, four classes for each year as described in Fig. 11 are created using the three years mean of A_0 and of A_1.

- Both A_0 and A_1 indicate higher values than the mean of A_0 and of A_1. (Class 1)
- A_0 indicates a higher value than the mean of A_0, and A_1 indicates a lower value than the mean of A_1. (Class 2)
- A_0 indicates a lower value than the mean of A_0, and A_1 indicates a higher value than the mean of A_1. (Class 3)
- Both A_0 and A_1 indicate lower values than the mean of A_0 and of A_1. (Class 4)

NDVI

1.0

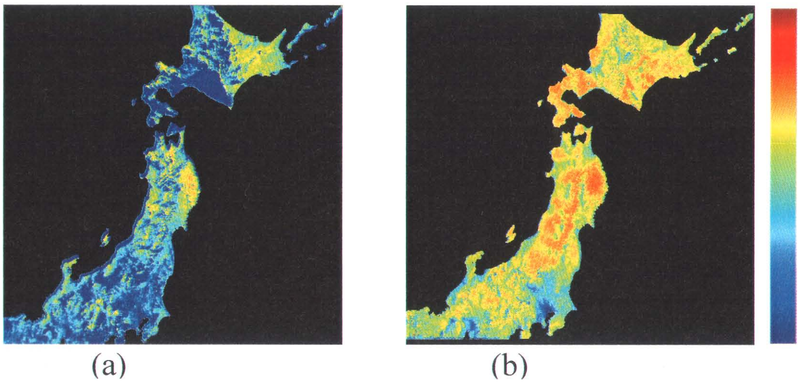


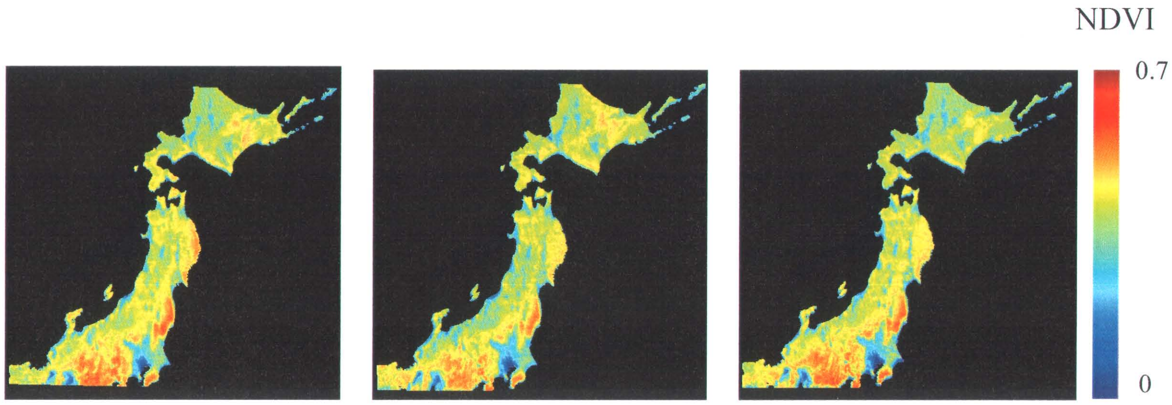
Fig. 12. (a) Daily NDVI image calculated from NOAA AVHRR dataset of 24 July 2004. (b) Monthly NDVI composite image of July 2004.

4. Results and Discussions

Daily NDVI images were calculated from NOAA AVHRR dataset for eastern Japan (January 2002 to December 2004). Subsequently 36 Monthly NDVI composite images were extracted from the daily NDVI images.

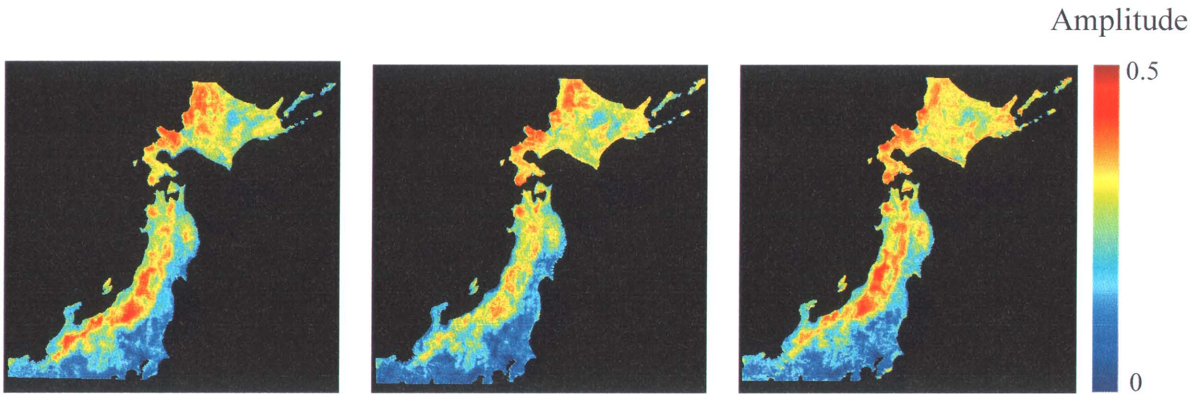
In the harmonic analysis for time-series NDVI data, we made three images; the additive term image, the amplitude and the phase angle image of the first harmonic term. Fig. 5 is the result of additive term images. In this result, we can find that the values of the additive term indicate high values in several areas in central Japan, and low values in Kanto region. High values indicate high total greenness over the course of a year, and low values indicate lower seasonal NDVI values. Fig. 6 is the result of amplitude images of the first harmonic term. We can find that amplitude values, especially in areas along the Sea of Japan, indicate high values. High amplitude values of the first harmonic term indicate a mono-modal temporal NDVI pattern. Fig. 7 is the result of phase angle images of the first harmonic term. Phase value ranges from 0 to 2π, corresponds from January to December. From Fig. 7 we can find that most phase values in each year show similar values, in other words that the time when maximum NDVI value occurs is similar.

The result of vegetation classification using the value of the additive term and the amplitude value of the first harmonic term is shown in Fig. 8. Class I, the regions where both A_0 and A_1 indicate high values, mostly appeared in areas along the Sea of Japan. Class II, the regions where A_0 indicate high values and A_1 indicate low values, mostly appeared in areas along the Pacific side.



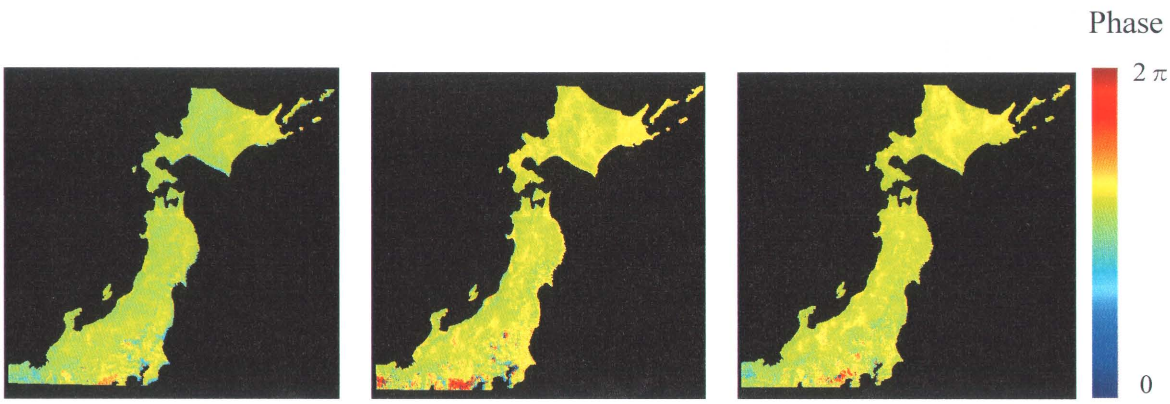
(a) 2002 (b) 2003 (c) 2004

Fig. 13. Additive term image (A_0)



(a) 2002 (b) 2003 (c) 2004

Fig. 14. Amplitude image of the first harmonic term (A_1)



(a) 2002 (b) 2003 (c) 2004

Fig. 15. Phase angle image of the first harmonic term (θ_1)

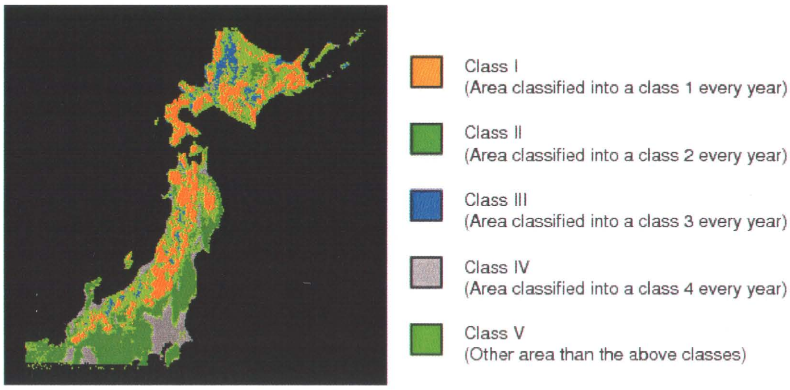


Fig. 16. Vegetation classification based on the value of the additive term (A_0) and the amplitude value of the first harmonic term (A_1).

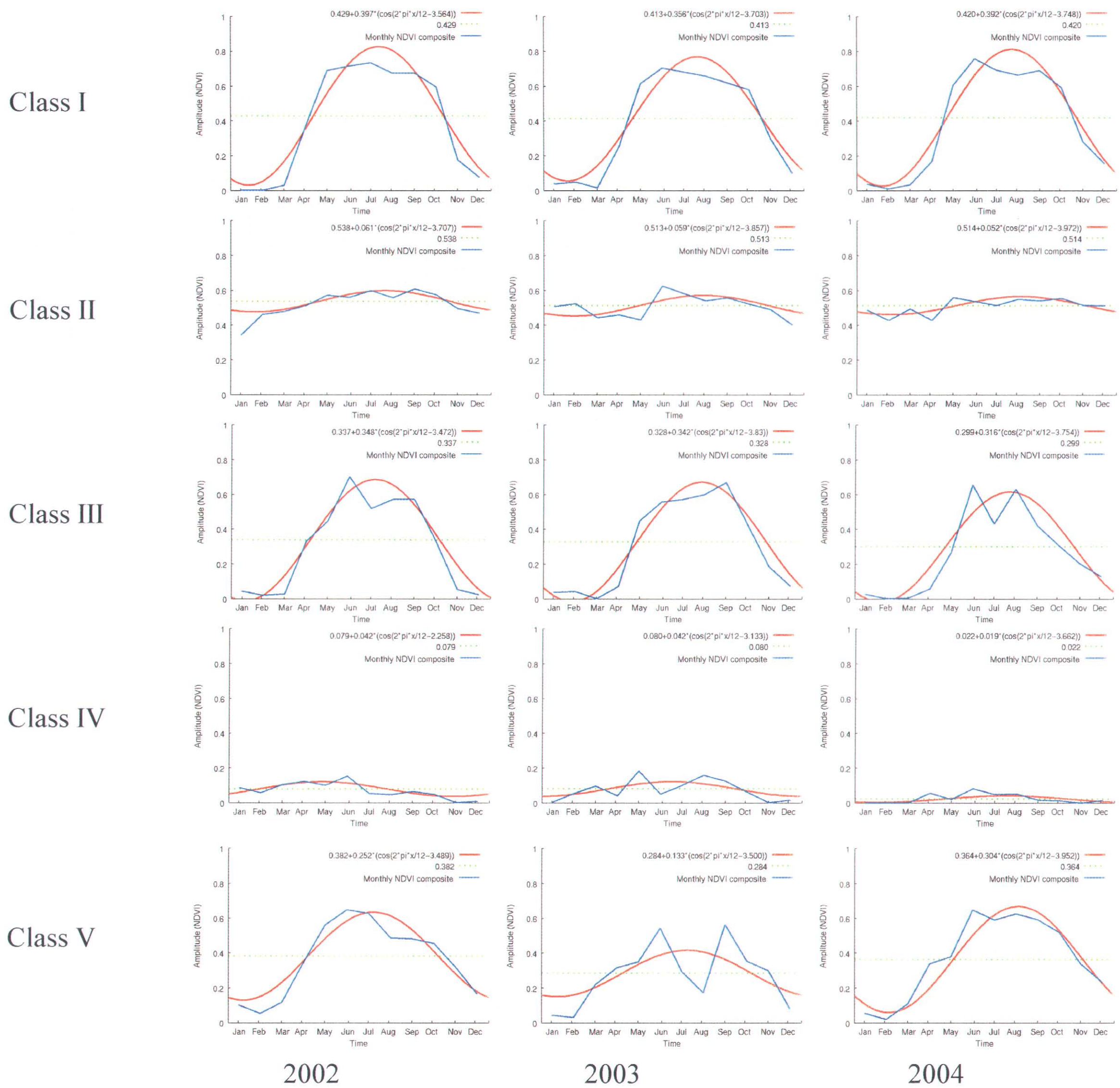


Fig. 17. Harmonic curves of the first harmonic term and monthly NDVI composite values in a representative point of each class

Fig. 17 shows the values of the additive term and the harmonic curves of the first harmonic term in a representative point of each class. In this result, we could confirm that the vegetation classification was performed correctly.

5. Conclusion

This paper has dealt with time-series analysis technique of remotely sensed imagery. We used NDVI as the vegetation index, and made NDVI images from the NOAA AVHRR dataset. Monthly NDVI composite images were extracted to reduce the effect of cloud contamination. Harmonic analysis is performed using monthly composite images within one year. Consequently, we computed the value of the additive term, and the amplitude value of the first harmonic term and the phase value of the first harmonic term, and could quantify some fundamental characteristics, related to the phenology of vegetation, from temporal sequences of NOAA AVHRR data. Finally, we could classify these characteristics into five vegetation types using these harmonic components.

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