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Identification of two common types of forest cover, *Pinus densiflora(Pd)* and *Querqus mongolica(Qm)*, using the 1st harmonics of a Discrete Fourier Transform

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Abstract : The time-series normalized difference vegetation index (NDVI) product has proven to be a powerful tool to investigate the phenological information because it can monitor the change of the forests with very high time-resolution. This study described the application of the DFT analysis over the 9 year MODIS data for the identification of the two types of vegetation cover, *Pinus densiflora(Pd)* and *Querqus mongolica(Qm)* which are dominant species of evergreen and broadleaved deciduous forest, respectively. The total number of samples was 5148 reference cycles which consist of 2160 *Pd* and 2988 *Qm*. They were extracted from the pixel-based MODIS scenes over the 9 years from 2000 to 2008 of South Korea. The DFT analysis was mainly focused on the 0th and 1^{st} harmonic components, each of which represents the mean value and the variation amplitude of the NDVI over the years, respectively. The 0^{th} harmonic values of the vegetation *Pd* and *Qm* averaged over the 9 years were 0.74 and 0.65, respectively. This implies that *Pd* has a higher NDVI than *Qm*. Similarly obtained 1^{st} harmonic values of *Pd* and *Qm* were 0.19 and 0.27, respectively. This can be intuitively understood considering that the seasonal variation of *Qm* is much larger than *Pd*. This distinctive difference of the 1^{st} harmonic value has been used to identify evergreen and deciduous forests. Overall agreement between the Fourier analysis-based map and the actal vegetation map has been estimated to be as high as 75%. This study found that the DFT analysis can be a concise and repeatable method to separate and trace the changes of evergreen and deciduous forest using the annual NDVI cycles.

Key Words : Vegetation identification, *Pinus densiflora(Pd)*, *Querqus mongolica(Qm)*, Time-series MODIS NDVI data, Discrete Fourier Transform.

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1. Introduction

In Korean peninsula, the annual mean temperature has been reported to rise by 1.5 degree Celsius during the past 100 years (Youn *et al.*, 2004). An additional increase by about 4 degrees is expected in the next 100 years (Ko *et al.*, 2006). If the temperature continues to rise, the coniferous forest will shrink, while the deciduous forest will spread further. A lot of pine trees are expected to be replaced by broad-leaved trees such as Oak (*Quercus spp.*). The Korea Forest Research Institute (KFRI) reported that the area of the mountain pine trees consistently decreased from 3.23million ha (49% of total forest) in 1974 to 1.5 million ha (23% of total forest) in 2007 (www.kfri.re.kr). Moreover, the sudden death of evergreen needle-leaf trees e.g. *pinus densiflora* and sub-alpine coniferous trees e.g. Abies koraiensis (*Abies koreana*) are reported quite frequently (www.yonhapnews.co.kr).

Vegetation growth pattern heavily depends on environmental conditions such as precipitation or atmospheric temperature. NDVI is an important parameter for climate change and long-term vegetation monitoring. The time-series NDVI data provide the intrinsic phenological characteristics of each vegetation type. These profiles contain more information than any measurement at a given point in time. The NDVI derived the satellite remotely sensed imagery have been used to analyze the biophysical vegetation characteristics, land cover classification, and the photosynthetic capacity (Tucker and Sellers, 1985; Loveland *et al.*, 1991). Recently the temporal sequence NDVI data provides more enhanced information about the vegetation phenology such as the timing, dynamics, and distribution of phytophenological events (Azzali and Menenti, 2000; Wang and Tenhunen, 2004). Vegetation types can be characterized by their seasonal (or phenological) variations in the NDVI time-series. For the time-series analysis of NDVI, the advanced very high resolution radiometer (AVHRR) at 1-km spatial resolution have been used from 1980' s, but they are being replaced by the improved spectral, radiometric, and geometric quality of MODIS images for the observation of global environmental changes. Even the well preprocessed MODIS NDVI data need to extract the intrinsic information of vegetation phenology from the original NDVI profile because they are affected by cloud cover, seasonal snow, and atmospheric variability. Fourier analysis is a good method for shape description of annual NDVI-cycles.

The Fourier (harmonic) analysis is useful for analyzing seasonal and interannual variation in land surface condition as recorded by NDVI profiles calculated from time-series remotely sensed data such as the AVHRR or MODIS (Jakubauskas *et al.*, 2002). The seasonal and intra-seasonal cycle of NDVI values can be highlighted by Fourier analysis and offers great promise for temporal variations of vegetation especially. The Discrete Fourier Transform has been successfully used by various authors to extract the periodic features, i.e., the harmonics of the time series NDVI data. Menenti *et al.*(1993), Andres *et al.*(1994), Olsson and Eklundh (1994), Azzali and Menenti(2000), and Moody and Johnson(2001) used the noise filterd NDVI cycles using Fourier Transform analysis and Discrete Fourier Transform has been successfully used by Evans and Geerken(2006), and Geerken(2009) to enhance the characteristics of the periodic features, i.e., the harmonics of the time series NDVI data. The Discrete Fourier analysis is an objective, consistent, and concise summarization of the temporal signature. Temporal signatures of remotely sensed vegetation indices provide one basis for image classification. That reveals systematic changes in vegetation but relatively insensitive to non-systematic data noise. In addition, the higher order harmonics of the Fourier components may capture the phenology of secondary vegetation components or rapid surface changes associated with Discrete event disturbances such as fire, deforestation, or flooding (Moody, 2001).

In the Korean peninsula, Cha(2010) estimated the amount of forest carbon sequestration using the 1st harmonics based on the Fourier Transform analysis and Cha *et al.*(2009a) and Cha *et al.*(2009b) calculated noise filtered NDVI-cycles using the harmonic analysis and used the smoothed outputs to monitor the onset date of the vegetation phenology. Park *et al.*, (2010) suggested the improved method of the NDVI noise interpolation using harmonic analysis. Kim *et al*(2011) used the vegetation interannualvariavility using harmonic analysis. Phenology, as expressed in pixel time trajectories, can also be used as a basis to partition surface cover into functional vegetation types, and there are several valuable properties associated with the use of Fourier analysis to analyze vegetation phenology.

The objective of this study is to present the technique as applied to identify the several common vegetation types, *Pinus densiflora(Pd)* and *Querqus mongolica(Qm)* in South Korea using the 1st harmonics of a Fourier Transform analysis of the time-series MODIS satellite imagery.

2.Methods

1) MODIS time-series NDVI data

This study presents a Fourier-based method for characterizing baseline intra-annual variability in vegetation productivity. The analysis is based on time series of 16 days composited NDVI data from the MODIS. Time series NDVI data are extracted from MOD13Q1 products (16-Day L3 Global 250m ISIN Grid VI data sets) covering Korean peninsula. The MODIS standard VI products include two, gridded vegetation indices (NDVI, EVI) and quality analysis (QA) with statistical data that indicate the quality of the VI product and input reflectance data. The VI products rely on the level 2 daily surface reflectance product (MOD09 series), which are corrected for molecular scattering, ozone absorption, and aerosols. The VI algorithms ingest the level 2G (gridded) surface reflectance and temporally composite these to generate the 16-day, 250/500 m or 1-km VI products. Once all 16 days of observations are collected, the MODIS VI algorithm applies a filter to the data based on quality, cloud, and viewing geometry (Heute *et al.*, 2002). The gridded vegetation indices include QA data sets with statistical data that indicate the quality of the VI products. The MODIS VI compositing algorithm includes three separate components: maximum value composite (MVC), constraint view angle – maximum value composite (CV-MVC), and bidirectional reflectance distribution function composite (BRDF-C) (Heute *et al.*, 1999).

In this work these data are acquired from February 2000 to December 2008 from the NASA Earth Observing System data gateway and there are two missing weeks for MODIS NDVI and QC (March 21, 2000 and July 27, 2004). The missing data are filled with values from the next week images. These products are geo-referenced using UTM coordinates using a nearest neighbour re-sampling routine and entered into a 231.70463m×231.70463m grid cell multilayer image stack. Then those data made subset with a latitude of 33°-43° and a longitude of 123°-133°.

2) Discrete Fourier Transform (DFT)

Using a DFT analysis, the NDVI cycle can be decomposed into its individual frequencies where each frequency is described by its individual magnitude and phase (Geerken, 2009). The DFT of any function f(t) with a period of T is given by

$$F_{(U)} = \sum_{t=0}^{N-1} f(t) e^{-2\pi iut/T} \quad (1)$$

Eq. (1) can be decomposed as a real part $F_c(u)$ (Eq. (2)) and an imaginary part $F_s(u)$ (Eq. (3)),

$$F_c(u) = \sum_{t=0}^{N-1} (f(t) \times \cos(2\pi \frac{ut}{T})) \quad (2)$$

$$F_S(u) = \sum_{t=0}^{N-1} (f(t) \times \sin(2\pi \frac{ut}{T})) \quad (3)$$

The MODIS data we used have been obtained every 16 days. In our DFT analysis, the data number t is the Julian day divided by 16, and f(t) is the NDVI data obtained at that Julian day. The period T is 23, that is, 365 divided by 16. The total number N of the t in a year is also 23.

The amplitude $F_{magnitude}(u)$ of each harmonics can be calculated as and the $F_{phase}(u)$ is given by

$$F_{Magnitude}(u) = \sqrt{F^2_c(u) + F^2_s(u)} \quad (4)$$

$$F_{Phase}(u) = \arctan\left[\frac{F_s(u)}{F_c(u)}\right] \quad (5)$$

By using the above Fourier components shown in Eq. (2) – Eq.(5), the time-series NDVI data f(t) can be expressed as

$$F(t) = \sum_{t=0}^{N-1} F_c(u)\cos(2\pi \frac{ut}{T}) + F_s(u)\sin(2\pi \frac{ut}{T})$$
$$= \sum_{t=0}^{N-1} F_{Magnitude}(u)\cos((2\pi \frac{ut}{T}) - F_{Phase}(u)) \quad (6)$$

$F_{Magnitude}(u)$ and $F_{Phase}(u)$ corresponds to the amplitude and phase of the u^{th} harmonics of the Fourier components, respectively. $F_{Phase}(u)$ reveals the shift of NDVI data in an time (t) axis. If the onset date of the vegetation growth is delayed for some reasons, for example, the $F_{Phase}(u)$ would be larger. $F_{Phase}(u)$ is a good indicator of the vegetation change in time domain, being very useful in the study of phenology. But it is not suitable for the classification of the forests between *Pd* and *Qm* because *Pd* and *Qm* is similar in time of maximum greenness. Thus we only considered $F_{Magnitude}(u)$ in this study.

$F_{Magnitude}(u)$ deals with the magnitude of the NDVI data. The $F_{Magnitude}(0)$ value corresponds to the 0^{th} harmonic term that has no t dependence. The constant value gives the arithmetic mean during a year. Thus, the images of the 0^{th} harmonic values ($F_{Magnitude}(0)$) match with the general patterns of land cover map. The high 0^{th} harmonic value indicates that the forest covers have a relatively high vegetation index.

The first harmonic value $F_{Magnitude}(1)$ indicates a temporally sinusoidal NDVI pattern with a period of a year. The larger is the annual change in the NDVI value, the bigger is the first harmonic value. Since the 1^{st} harmonic value represents the amount of variation throughout a year, the value of the evergreen forests is expected to be much smaller than that of deciduous forests. The map of the 1^{st} harmonic values of NDVI can give the distinctive difference between evergreen and deciduous forests. This is the main point of this paper. We obtained the map of the 1^{st} harmonic values of the NDVI from the time-series MODIS satellite images, and compared it with the locations of the evergreen and deciduous forests in Korean peninsula.

The second harmonic value $F_{Magnitude}(2)$ gives the NDVI pattern with a period of a half year. The map of $F_{Magnitude}(2)$ can give the locations where the vegetation changes with a period of half year, for example, double-cropping area. This is also very interesting topic, and will be addressed in another publication.

3) Sampling sites

This study focus on two types of forest cover, *Pinus densiflora(Pd)* and *Quercus mongolica(Qm)* which are dominant species of evergreen and broadleaved deciduous forest of the country, respectively. The main forest type of South Korea is composed by evergreen, deciduous and mixed forest. The areal percentages of forest composition for

Table 1. The area of *Pinus densiflora (Pd)* and *Querque mongolica (Qm)*, which is the dominant species of the actual vegetation map

Community	Area(ha)		Ratio (%)	
Broad-leaved forest in mountainous area	1,560,729		48.69	
Quercus mongolica(Qm)		762,034		23.77
Mixed forest with *Qm*		230,527		7.19
Qm and Mixed forest with *Qm*		992,560		30.96
Others without *Qm* and Mixed forest with *Qm*		568,169		17.73
Needle leaf forest in mountainous area	1,586,926		49.51	
Pinus densiflora(Pd)		928,197		28.96
Mixed forest with *Pd*		473,739		14.78
Pd and Mixed forest with *Pd*		1,401,936		43.73
Others without *Pd* and Mixed forest with *Pd*		184,989		5.78
The Others	57,929		1.8	
Total	3,205,584		100	

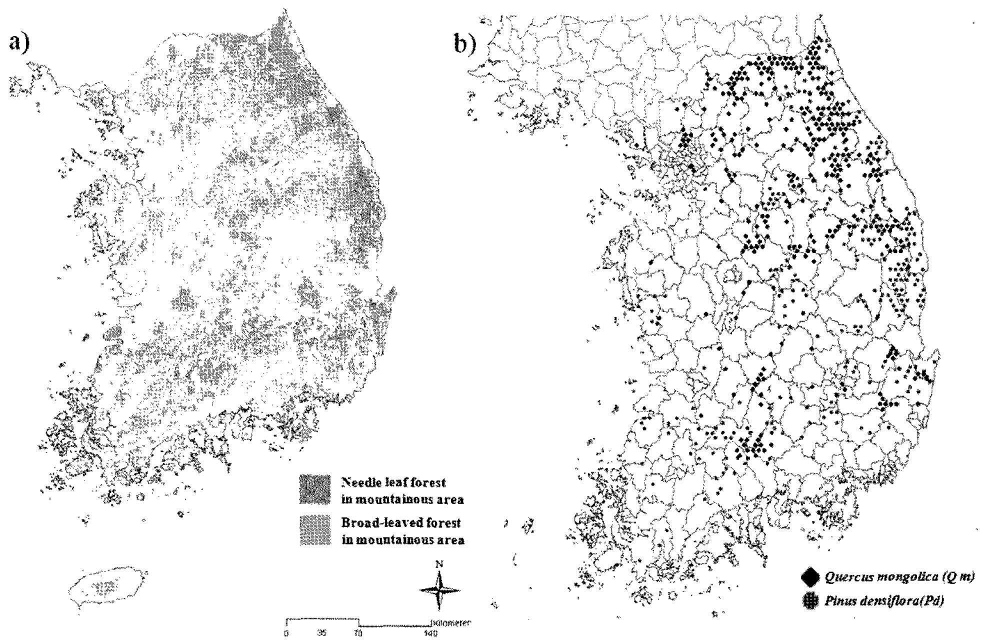

Fig. 1. a)The Actual vegetation map of South Korea. b)Sample points for the validation of vegetation classification.

evergreen, deciduous and mixed forest are 42%, 25%, and 29%, respectively. While the forest type map does not describe the specific species of the forest, the actual vegetation map(Fig. 1a) provided by the Ministry of Environment in 2006 has a description of the specific kinds of plants which actually exists at the time of observation regardless of the character, condition, and stability of its component communities. The actual vegetation map shows that the vegetation of South Korea consists of 170 communities (www.me.go.kr), where the Broad-leaved forest and Needle leaf forest in mountainous area are 48.69%, 49.51 respectively (Table 1).

The homogeneous communities of *Pd* and *Qm* have been used to extract the accurate sample points. This sampling process was based on Actual vegetation map and high resolution imagery by Google earth (Cha and Park, 2007). The total number of samples is 5148 reference cycles which are 2160 and 2988 in case of *Pd* and *Qm*, respectively (Fig. 1b). They were selected over a 10-year period of forest vegetation of South Korea by about 3minutes interval (about 5km) based on random point generator of Repeating shapes for ArcGIS (http://www.jennessent.com/).

3. Analysis and Results

The results can be summarized as follows. Table 2 shows the 0^{th} and 1^{st} harmonic values of *Pinus densiflora(Pd)* and *Querqus mongolica(Qm)* averaged over the 9 years, respectively. The 0^{th} harmonic values of *Pd* and *Qm* are 0.74 and 0.65. The 1^{st} harmonic values of *Pd* and *Qm* are 0.19 and 0.27. The normalized difference ratios between the *Pd* and *Qm* are 6.47 % ((0.74 – 0.65)/(0.74 + 0.65)) and 16.7% ((0.27 – 0.19)/(0.27 + 0.19) in 0^{th} harmonic and 1^{st} harmonic values, respectively. This indicates that 1^{st} harmonic value is about three times better than 0^{th} harmonic value in classifying *Pd* and *Qm*. *Qm* has much higher in 1^{st} harmonic value than *Pd*. *Pd* has leaves even in winter season and continues its vegetation function but *Qm* loses their leaves during winter season.

Fig. 2 shows the band filtered time-series NDVI data that shows only the 1^{st} harmonic variation with a period of a year. It is obtained by putting u=1 in Eq. (6). Fig. 2a shows the *Qm* (blue) and *Pd* (margenta) data averaged over the 9 years. Fig. 2b and Fig. 2c depicts the individual 9-year data of *Qm* and *Pd*, respectively. Although *Pd* and *Qm* exhibit distinctive difference in 0^{th} and 1^{st} harmonic amplitude values, the 1^{st} harmonic phase values are similar. This indicates that the amplitude value of the 1st harmonic is the more suitable than the phase value for the classification of the *Qm* and *Pd*.

Fig. 3 shows the histogram of the 1^{st} harmonic

Table 2. The average values of 9 years for the 0^{th} and 1^{st} harmonic term values of *Pd* and *Qm*

Amplitude \ Species	Pinus densiflora (Pd)	Querqus mongolica (Qm)
0^{th} harmonic term	0.74	0.65
1^{st} harmonic term	0.19	0.27

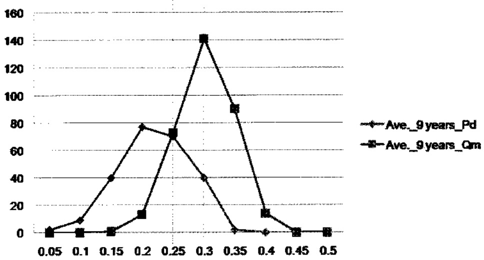

Fig. 3. Frequency table of two types of vegetation from 2000 to 2008

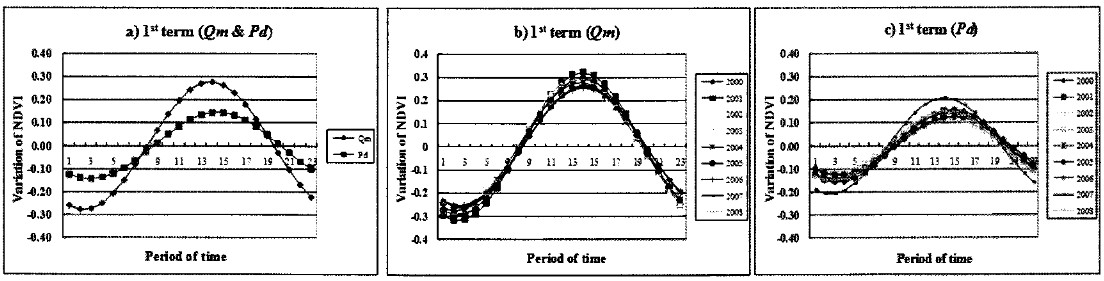

Fig. 2. a) The comparison of the 1^{st} harmonics averaged over 9 years of *Qm* and *Pd* b) the first harmonics of *Qm* c) the first harmonics of *Pd*

amplitude values of *Qm* and *Pd*. From this plot, one can find the best decision boundary for the classification between *Pd* and *Qm*. It is 0.25 where the 1st harmonic amplitudes have similar values in *Pd* and *Qm*.

The classification maps using the 1st harmonic decision boundary of 0.25 are shown in Fig. 4. The green and brown color shows the Pd and *Qm*, respectively. The other colors represent the vegetation types which are not classified as *Pd* or *Qm*. Comparing the map shown in Fig. 4 with the actual vegetation map shown in Fig. 1a, one finds that they

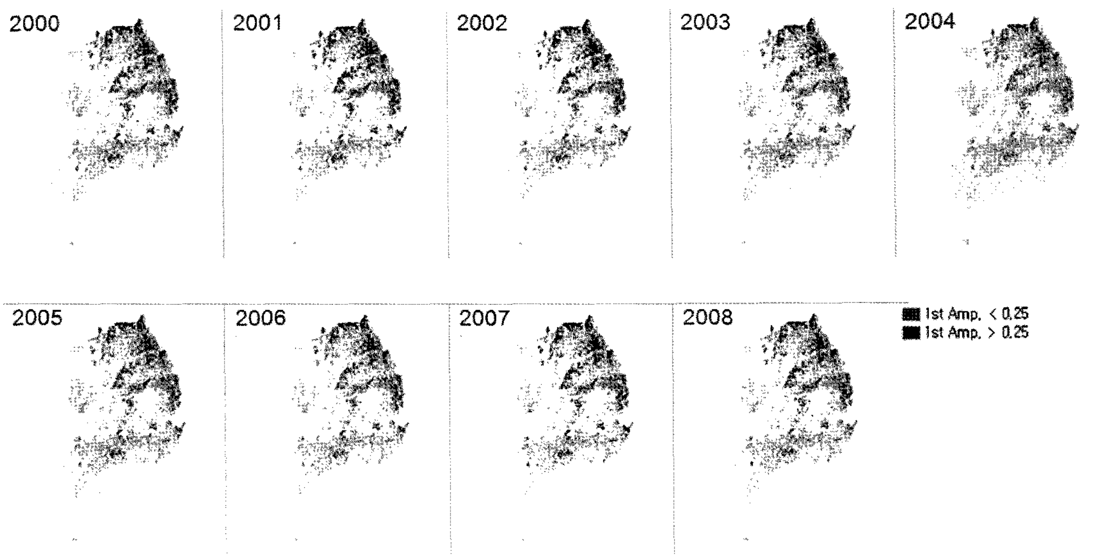

Fig. 4. The vegetation map with 0.25 threshold of the 1st amplitude value from MODIS NDVI, in South Korea; The green color shows *Pd*, the brown color shows *Qm*, and the yellow color shows the others ; The distribution of 1st amplitude value with threshold 0.25 is similar to the actual vegetation map.

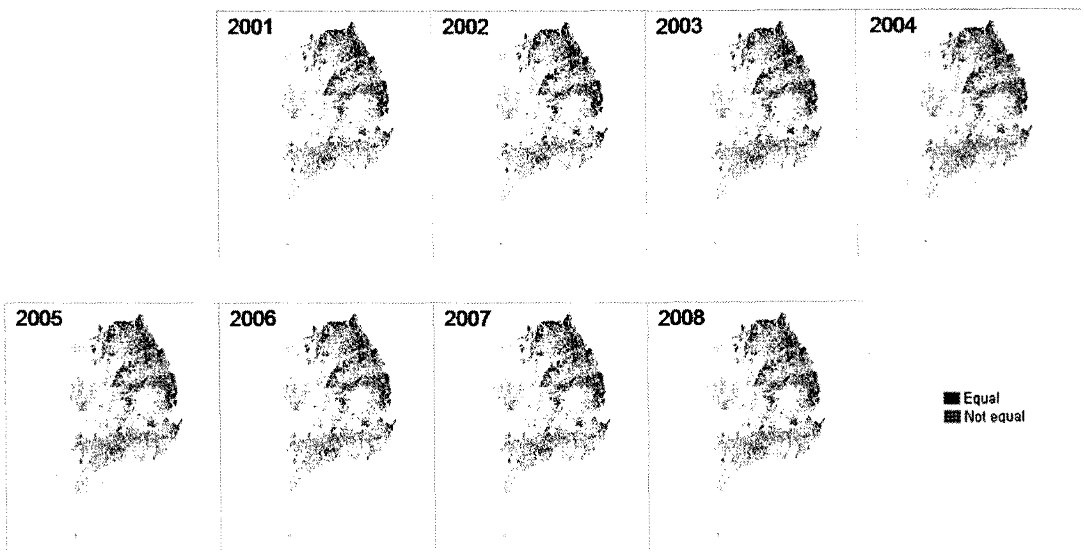

Fig. 5. The comparison with the actual vegetation map and the 1st harmonic amplitude image of Pd and Qm.

Table 3. Area comparison of the actual vegetation map and the 1st harmonic amplitude image of Pd and Qm.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	Average
Equal	75.16%	75.82%	78.50%	74.88%	74.56%	75.30%	71.99%	73.46%	74.55%	74.91%
Not equal	24.84%	24.18%	21.50%	25.12%	25.44%	24.70%	28.01%	26.54%	25.45%	25.09%

look similar. For the quantitative estimation of accuracy of the classification, we compared the 1st harmonic (threshold = 0.25) map in Fig. 4 with the actual vegetation map (reference map) in Fig. 1a. The positions where the classifications are not equal have been detected as in Fig. 5 and the areal ratio have been estimated as in Table 3. The estimated accuracy is about 75 %, which is similar to the conventional method based on scene statistics. Conventional method involves the subjective of the expert, and ad-hoc corrections. The classification algorithm is not clearly fixed. Considering this fact, our method based on the 1st harmonic amplitude is much simpler and objective. The procedure for the classification is quite universal, that is, the result is the same irrespective of the person performing it. Due to this universality, our method can be a world-standard for the rough classification for the *Pd* and *Qm*.

4. Conculsion

This study describes the application of Discrete Fourier Transform to the multiple year (2000~2008) of MODIS data (23 periods individually per one year) for identification of two common types of forest cover, *Pinus densiflora(Pd)* and *Quercus mongolica (Qm)* which are dominant species of evergreen and broadleaved deciduous forest of the South Korea. This study finds that the DFT analysis of the annual NDVI cycles contributes to the separation of evergreen and deciduous forest. The deciduous forest yields higher first harmonic value than evergreen forest. This fact has been used to classify them. By surveying the 9-year time series MODIS satellite images over the 5148 reference sites, where the vegetation type is already known through the actual vegetation map, we can obtain maps classifying *Pd* and *Qm* and compare them with the reference data. Overall agreement between the Fourier-based map and the actual vegetation map has been estimated to be 75%. Given the adequate data, the DFT approach provides a concise and repeatable method for summarizing baseline inter-annual variability of vegetation dynamics and classifying basic vegetation formations.

The forest map updated in a period of 5~10 years could not detect the continuously changing vegetation condition. Conventional method of forest classification based on direct on-site observation takes long time and is not suitable for monitoring the vegetation change continuously. Compared to the on-site observation, the multitemporal satellite image-aided analysis based on the Fourier analysis is much more efficient because the satellite images are updated every day. If a suitable algorithm for the classification of the forest types is devised, the time-series data can be applied to the continuous detection of the vegetation change with a very high time resolution. Our classification method can be used to assess repeatedly the long-term vegetation changes due to the human activity and the global warming.

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