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Global scale assessment of the relative contribution of climate and non-climate factors on annual vegetation change

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The impact and its change on the Earth's biosphere from climate and non-climate factors are of grave concern due to increasing human activities. In this study we used a systematic method to assess the relative importance of climate and non-climate factors on annual global and continental vegetation dynamics based on global NDVI at 1-km resolution and surface climate data from main stations of the World Meteorological Organization between April 1998 and December 2002. The indices of relative importance of climate and non-climate fluctuations on vegetation dynamics at each continent before and after July 2000 (two equal time periods) were also compared. Our results indicated that the vegetation dynamics on a continental and global scale during this short time period was dominated by climate fluctuations, however, the relative importance of climate and non-climate factors on yearly vegetation dynamics differed among continents. Despite the dominant role of climate on vegetation dynamics during these two time periods for all continents, the relative importance of climate on vegetation dynamics increased slightly in south-east Asia, North America, Africa, Australia and New Zealand, but decreased slightly in South America, Central America, west Asia, north Asia, Europe and globally. This method may be helpful in monitoring the impacts from climate and non-climate factors on global vegetation dynamics.

Keywords: Continents, global vegetation dynamics, NDVI, relative importance of climate and non-climate factors

1. Introduction

Global vegetation is important for maintaining biosphere functions. However, vegetation is also important for human populations in providing food, fuel and ecological services. At a large spatial scale, climate was considered to be the dominant factor for vegetation change (Holdridge, 1947; 1967). However, with an increase in human population and the potential technology, land use change and vegetation change on earth surface contributed from human and other non-climate factors have become seriously, such as deforestation and desertification (e.g., Maloney, 1997; Kharin, 2002). Climate is also indirectly affected by human influences due to feedback (e.g., Karl and Trenberth, 2003; Karoly et al., 2003). In order to better study global vegetation change, it is important to separate the impacts of global climate from non-climate factors. Does climate still dominate vegetation change at large scales? Properly assessing the influences of climate and non-climate factors on global vegetation dynamics is necessary for current global change research, but a challenge because of its complexity (Vitousek et al., 1997; Whitlock and Bartlein, 1997). However, it is important to understand global climate, vegetation change and impact of human activities, and also to better inform our environmental decision-makers (AIBS, 2004). The need for improved information and understanding of land use and land cover dynamics in order for society to respond effectively to environmental changes and to restrict our human impacts on earth environmental systems has been identified as one of the six grand challenges for The National Ecological Observation Network to consider (NRC, 2003).

De Menezes and Barabási (2004) proposed a systematic method to separate the relative importance of internal and external factors in complex systems based on multiple time series from a number of components which interact with each other. Their method was used successfully to determine the original dynamics in various mechanical systems. The aim of this study is to apply this method to assess the relative importance of climate and non-climate factors on annual global vegetation dynamics (e.g., NDVI) at a continental scale and to compare the relative importance of climate factors on vegetation at different continents.

2. Material and methods

2.1 Data

Normalized Difference Vegetation Index (NDVI) is an intensively used satellite vegetation index (Pettorelli et al., 2005) that provides a convenient measure for underlying ecological processes, such as plant growth, vegetation cover and biomass production (e.g., Asrar et al., 1984; Fung et al., 1987). The principle behind NDVI is that chlorophyll absorbs incoming sunlight in the red-light region of the electromagnetic spectrum while plant leaf mesophyll creates consideration reflectance in the near-infrared region (Tucker, 1979; Tucker et al., 1991). As a result, vigorously growing healthy vegetation has high NDVI values. Global NDVI at 1-km resolution was obtained from SPOT Vegetation VGT–S10 (10-day synthesis product) data (http://www.vgt.vito.be) from April 1998 to December 2002. This data set was atmospherically corrected for ozone, aerosols and water vapor (Rahman and Dedieu, 1994). There are three 10-day composites for each month: days 1–10, 11–20, and 21 to the last day of a month. VGT-S10 data were generated by selecting pixels that have the maximum NDVI values within a 10-day period. This approach could minimize the effect of cloud cover and variability in atmospheric optical depth. The NDVI values of 1-km^2 resolution were aggregated at the continental level through the sum of NDVI values from all 1-km^2 areas within each continent (Table 1). We also chose the maximum NDVI value from three 10-day composites to represent the monthly NDVI for each continental area.

The monthly global surface climate data of 3 100 stations worldwide maintained by the World Meteorological Organization were downloaded from National Climate Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html). Based on the literature (e.g., Holdridge, 1947 and 1967; Field, 1995), it can be assumed that vegetation on a large scale is mainly controlled by air temperature, precipitation and sunshine time. Therefore, here we only used monthly mean air temperature, total precipitation and sunshine duration to represent climate in this analysis.

2.2 Method of Comparing Climate and Non-Climate Contribution

The dynamics of global vegetation is supposed to be attributed by two main factors: (i) climate factors (e.g., temperature and precipitation) and (ii) non-climate factors (e.g., human land use and insect or disease damage). If we consider that climate factors are external factors to the continental vegetation system, then non-climate factors can be considered as internal factors. Because human beings live on the earth's surface with vegetation and they are a part of ecosystems. Their impacts could be considered as internal to the vegetation systems at a continental level; while atmosphere is above the earth's surface and vegetation systems, the impacts from atmosphere (or climate) could be considered to be external although there are interactions between vegetation and climate. This is consistent with ecosystem view that all organisms are components of an ecosystem but climate is external factor (e.g., Chapin et al., 2004). Due to the complexity between climate, non-climate factors and global vegetation dynamics, such as irrigation, crop rotation and wildfires, it is impossible to quantitatively separate each factor. Moreover, it is difficult to assess the contribution of each factor at a larger scale. Based on the research of a general system from De Menezes and Barabási (2004) we can separate the two contributions for each component i (i from $1,\ldots, N$) at each continent by using the following:

$$f_i(t) = f_i^{c}(t) + f_i^{nc}(t)$$

Here the superscript c and nc mean climate and non-climate. The number of component N is 3 here, because the climate factors that can influence vegetation change were considered to be mainly controlled by air temperature, precipitation and duration of daylight. Based on the method proposed by De

Menezes and Barabási (2004), we can estimate the ratio of the total fluctuations without detailed knowledge of the vegetation system's dynamical rules and feedbacks by going through the all observed N components at the continent scale in the time interval $t \in [0,T]$ (here t is from April 1998 to December 2002) using the following

$$A_i = \frac{\sum_{t=1}^{T} f_i(t)}{\sum_{t=1}^{T}\sum_{i=1}^{N} f_i(t)}$$

If only climate fluctuations contribute to the activity of node i, then at any moment t the amount of fluctuation to go through node i is estimated by the product A_i and the total fluctuation in the system at moment t as follows:

$$f_i^c(t) = A_i \sum_{i=1}^{N} f_i(t)$$

then

$$f_i^{nc}(t) = f_i(t) - A_i \sum_{i=1}^{N} f_i(t)$$

For each recorded signal i the climate and non-climate standard deviations (σ_i^c and σ_i^{nc}) and their ratio (η_i) can be calculated,

$$\eta_i = \frac{\sigma_i^c}{\sigma_i^{nc}}$$

When $\eta_i >> 1$, the climatic fluctuation dominates the vegetation dynamics of component i, while for $\eta_i << 1$ the vegetation dynamics are dominated by the imposed non-climate changes (De Menezes and Barabási, 2004).

3. Results and discussion

The vegetation dynamics for different continents and the entire earth were mainly controlled by fluctuations of climate factors because $\eta_i >> 1$ (Table 1) for all continents. However, there were differences in the relative importance of climate fluctuations on vegetation dynamics among different continental areas. Climate fluctuations had the highest influence on vegetation dynamics in south-east Asia, but had the least influence in Europe, Africa and South America. As expected climate factors influenced vegetation dynamics less in Europe in comparison with the other continents because of its intensive land use change; the lower influence of climate on vegetation dynamics at

Central and South America might be related with large scale deforestation (e.g., Lawton et al., 2001). However, it is surprising that climate fluctuations played the most important role on vegetation dynamics in south-east Asia as we originally thought the huge population in south-east Asia (e.g. China) and their activities might deeply affect the vegetation dynamics there. The highest influence of climate factors on the vegetation in south-east Asia might be related with the strong activities of monsoons in this area. The relatively less dense and less high configuration of cities in south-east Asia and north Asia compared to the United States might be also one of causes (Bonnan, 2002).

We also compared the relative influence of climate factors at different times by just simply dividing the studying time into two equal periods, before and after July of 2000. Although climate factors still dominated vegetation dynamics at the continental and global level during these two time periods, we found that the relative importance of climate factors on vegetation dynamics increased slightly on the south-east Asia, North America, Africa, Australia and New Zealand, and globally (Table 1); but the relative importance of climate factors decreased slightly on the other continents, such as South America and west Asia. By calculating this index at different time periods we may monitor the rate of non-climate influence (such as human activities) on vegetation dynamics at regional or global scale.

Table 1. Basic information of different continents and their η_i values

Continent	Extent		η_i value	η_i value	
	Latitude (Degree N)	Longitude (Degree E)		Before July 2000	After July 2000
South-East Asia	5 – 40	68 – 147	9998	7229	7649
South America	–56 – 25	–93 – (–33)	32	32	29
Central America	0 – 40	–125 – (–50)	49	63	59
West Asia	5 – 50	25 – 98	99	160	150
North Asia	40 – 75	45 – 180	1407	16658	1249
North America	40 – 75	–180 – (–13)	99	124	130
Africa	–35 – 38	–26 – 60	32	33	35
Europe	25 – 75	–11 – 62	32	34	33
Australia and New Zealand	–48 – 10	95 – 179	99	85	86
Globe	Above all		49	64	63

In conclusion, at the continental and global scale vegetation dynamics are still dominated by climate fluctuation which can help us to understand continental vegetation change, such as ecotone areas around biomes, but the relative importance of climate and non-climate influence on continental and global vegetation dynamics may be different at short time period (such as yearly). By using this method at different scales or different vegetation types, it is possible to monitor the rate of change in the relative importance of climate and non-climate factors on local, regional and global vegetation dynamics, especially to infer impact of non-climate factors, such as human activities.

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SAŽETAK

Globalna procjena relativnog doprinosa klimatskih i neklimatskih čimbenika godišnjoj promjeni vegetacije

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Utjecaj klimatskih i neklimatskih čimbenika na Zemljinu biosferu, kao i njihove promjene, izazivaju ozbiljnu zabrinutost zbog porasta ljudskih aktivnosti. U ovoj studiji koristili smo sistematsku metodu za procjenu relativne važnosti klimatskih i neklimatskih čimbenika na godišnju ukupnu i kontinentalnu dinamiku vegetacije na osnovi ukupnog normaliziranog indeksa razlike u vegetaciji (NDVI – Normalized Difference Vegetation Indeks) uz rezoluciju od 1 km i prizemnih klimatskih podataka iz mreže glavnih postaja Svjetske meteorološke organizacije u razdoblju od travnja 1998. do prosinca 2002. godine. Također su uspoređeni indeksi relativne važnosti klimatskih i neklimatskih fluktuacija na dinamiku vegetacije svakog kontinenta prije i poslije srpnja 2000. godine (dva razdoblja iste dužine). Naši rezultati ukazuju da dinamikom vegetacije na kontinentalnoj i globalnoj skali tijekom ovoga kratkog vremenskog razdoblja dominiraju klimatske fluktuacije. Međutim, relativna važnost klimatskih i neklimatskih čimbenika na godišnju dinamiku vegetacije se razlikovala od kontinenta do kontinenta. Unatoč prevladavajućem utjecaju klime na dinamiku vegetacije u ova dva kratka razdoblja na svim kontinentima, relativna važnost klime na dinamiku vegetacije blago je porasla u jugoistočnoj Aziji, Sjevernoj Americi, Africi, Australiji i Novom Zelandu, ali je blago smanjena u Južnoj i Centralnoj Americi, zapadnoj i sjevernoj Aziji i Europi te globalno. Ova metoda može biti korisna pri praćenju utjecaja klimatskih i neklimatskih čimbenika na globalnu dinamiku vegetacije.

Ključne riječi: Kontinenti, globalna dinamika vegetacije, NDVI, relativna važnost klimatskih i neklimatskih čimbenika

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