Shifts in vegetation growth in response to multiple factors on the Mongolian Plateau from 1982 to 2011

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Abstract

The Mongolian Plateau (MP) steppe is one of the largest steppe environments in the world. To monitor the terrestrial vegetation dynamics on the MP and to ascertain what the driving forces, this study examined the vegetation dynamics in Republic of Mongolia (M) and the Inner Mongolia Autonomous Region (IM) of China from the period 1982 to 2011, based on the satellite-derived GIMMS NDVI3g (Normalized Difference Vegetation Index) data across three biomes (desert, grassland and forest). The results are as followed: (1) Vegetation coverage in IM was generally greater than that in M. Before 2002, time series of NDVI over the MP increased at an average rate of 0.05% yr⁻¹. Additionally, after 2002, the NDVI increased at a rate of 0.21% yr⁻¹. From 1982 to 2011, the area of IM and M with positive anomalies in the NDVI increased at a separate rate of 1.82% yr⁻¹ and 1.76% yr⁻¹, respectively. (2) At the biome scale, the inter-annual forest NDVI variation in IM and desert NDVI for the entire MP had a significant increasing trend (0.06% yr⁻¹ and 0.04% yr⁻¹, respectively). (3) Climate forcing was a dominant controlling factor affecting the vegetation, and the anthropogenic behavior exhibited no significant value in the whole region. However, overgrazing was the most important reason for the regional degradation, particularly in IM. (4) In the future, the forest biome will go to recovery, whereas both the grassland and desert biomes are predicted to degrade continuously.

Keywords: Mongolian plateau, vegetation growth, biomes, climate change, human interventions

1. Introduction

Global warming and extreme climatic events are major threats for terrestrial ecosystems, particularly in arid and semi-arid regions (Jiménez et al., 2011; Lloret et al., 2012). Vegetation growth has received considerable attention due to its ecological vulnerability, its high sensitivity to climate change, external disturbances (Fensholt et al., 2009; Jugder et al., 2011; Lioubimtseva et al., 2005; Liu et al., 2008; Van Keulen and Breman, 1990) and its important role in the global carbon cycle (Still et al., 2003). In particular, as predominately demonstrated by population growth and by anthropogenic climate change (i.e., the growth rate of atmospheric CO₂), vegetation growth is altered even more directly and drastically worldwide (Cook et al., 2013; Walther et al., 2002; Zhen et al., 2010a). According to the latest IPCC AR5 summary for policymakers, historical temperatures have presented a warming of 0.85 (0.65-1.06)°C over the period from 1880-2012 (Buckle and Mactavish). Therefore, there is an increasing requirement for detecting, understanding, and predicting ecosystem variations in arid and semi-arid regions, and these variations can provide early warnings of ecosystem degradation (Cao et al., 2013; Pettorelli et al., 2005).

International research has focused more attention on the Mongolian Plateau (MP) in recent years (John et al., 2013; Sneath, 1998, 2000). One significant mark of this global concern has been the increasing number of scientific studies regarding natural and social-economic aspects focused on the MP (Sneath, 1998, 2000). Natural disasters, such as *dzuds*, dust storms, desertification, overgrazing and soil erosion, more frequently threaten its pastoralists' and herds' survival and influence the land surface via hydrological, biogeochemical processes directly and timely in this region (Cao and Woodward, 1998; John et al., 2013; Mu et al., 2013; Tietjen et al., 2010), the climate system in eastern Mongolia and in northeastern China was shown to be getting warmer and drier (Li et al., 2008). Harsh droughts occurred over the plateau from 1999 to 2001, in 2005 and in 2009 over most of the country, resulting in devastating livestock losses (Davi et al., 2013; John et al., 2013). Sneath reported an overview of state policies and land degradation statuses in Inner Asia, primarily focusing on Russia, Republic of Mongolia (M) and on Inner Mongolia (IM), and noted different land degradation degree changes under entirely different political and economic policies (Sneath, 1998). Above all, monitoring the vegetation changes in the steppe areas will be crucial to indigenous pastoralists who rely on stock farming.

Several studies have explored the relation between vegetation, human activity and climate factors in the entire plateau, and vegetation variation was primarily attributed to the eastern Asia monsoon system and to the total annual precipitation (Bao et al., 2013; Cao et al., 2013; Chen and Wang, 2009; Schimel, 1995), whereas Yang et al. (2011) thought the NDVI and temperature were the closest factors, followed by precipitation, sunshine hours and relative humidity (Yang et al., 2011).

In addition to natural factors, according to Hilker's study, 80% of the decline in grassland in M was due to overgrazing induced by increases in livestock from 2002 to 2012 (Hilker et al., 2013). However, most of the studies focused on one single aspect (temperature, precipitation or human activity) affecting a single temporal trend or spatial trend and lacked long-term data. To our knowledge, few studies attempted to separate the pressure from climate and population on the local people's environment and on conditions on this plateau. To gain a better understanding of vegetation dynamics in dry areas with different land management practices, it is essential to analyze the land use, climate, human activity and national policy to overcome this shortcoming.

Understanding how the vegetation of arid and semiarid ecosystems responds to multiple factors is crucial for regional sustainable development of environment and economy. In this research, the newest global vegetation dataset GIMMS NDVI3g and CRU (Climatic Research Unit) grid data are applied to examine the spatiotemporal information concerning vegetation activity dynamics from 1982-2011 over the MP. Then, we present how the vegetation response to climate change and to anthropogenic activity varies between M and IM. Using Mann–Kendall trend tests, greenness anomalies, and the Hurst exponent and linear regression methods, our study investigates the following issues: (1) Has the vegetation decreased or increased in spatiotemporal distribution across different ecosystem biomes in recent years? (2) Are there any different effects of climate and anthropogenic factors on the vegetation between the two political units: IM and M? (3) What will be the vegetation status in the immediate future?

2. Material and methods

2.1 Study area

The entire area of the MP constitutes of the M (relatively small population: 2.9 million in 2013) and IM (relatively large population: 25 million in 2013) in the eastern part of the Eurasian continent, with an average elevation of 1600 meters (Figure 1) (Miao et al., 2014b). The areas of IM and M are 1.18 billion sq. km and 1.56 billion sq. km, respectively. The vegetation could be divided into three biomes with obvious boundaries, according to Olson's global terrestrial ecoregions (Gobi desert in the west, grassland in the middle and forest in the northern and eastern part) (Olson et al., 2001). The MP steppe is one of the largest remaining grassland ecosystems controlled by the continental climate (Li et al., 2008; Mason et al., 1999). Climate is extremely cold in the winter and hot in the summer with an average precipitation of 200 mm yearly. Livelihoods in M and in IM are primarily based on livestock and grassland resources, with most of the region covered by desert along with sparse vegetation and grasslands (Olson et al., 2001). The MP provided an entirely new area for understanding how pastoral peoples interact with these northern, interior, and steppe-desert

environments (John et al., 2013; McColl, 2002). Both IM and M experienced a similar arid and semi-arid climate but had different anthropological influences via their separate social and economic development histories (Sneath, 1998, 2000).

2.2 Material

NDVI is a common indicator to track vegetation productivity and vegetation growth at regional or global scales (Fensholt and Proud, 2012; Fensholt et al., 2009; Peng et al., 2011; Piao et al., 2006). Global satellite-derived data have been widely applied in vegetation diagnosis in regional areas (GIMMS/AVHRR, MODIS, SPOT etc.) (Jiang et al., 2013; Mu et al., 2013; Wang and Li, 2011). Discrepancies exist in the performance of the three listed global datasets; however, GIMMS/AVHRR has been proven to be convincing and the longest dataset applied on the MP (Miao et al., 2013a). The GIMMS 15-Day (Global Inventory Modeling and Mapping Studies) composite of the NDVI3g dataset was acquired by the NOAA (National Oceanic and Atmospheric Administration) satellite for a 30 year period spanning from 1982 to 2011 processed by the NASA (National Aeronautics and Space Administration). GIMMS NDVI3g is a new generation of the GIMMS NDVI dataset, with a spatial resolution of 8 km. Several studies have demonstrated that GIMMS NDVI3g represents more accurate responses of vegetation to climate variability and are more useful for global models than the older generation models (Jiang et al., 2013; Zeng et al., 2013).

In this study, monthly data of meteorological elements (temperature and precipitation) from CRU (Climatic Research Unit) (<http://www.cru.uea.ac.uk/>) are applied to analyze the climate influence because the meteorological station data are unevenly spatially and temporally distributed in this area. This dataset has a resolution of 0.5° extending from the 1850s to 2012, and these data were often used in applied climatology, biogeochemical modeling, hydrology and agricultural meteorology studies (New et al., 2002). Before the analysis, we resampled the grid data into 8km to be consistent with the NDVI data.

2.3 Methods

2.3.1 Greenness anomaly

The greenness anomaly derived from the vegetation NDVI (equation 1 & 2) is a detrended method to examine how the vegetation varied from the average level in the year i and applied in monitoring the spatial pattern of vegetation growth (John et al., 2013; Lotsch et al., 2005; Peng et al., 2011). The equation is as follows:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad (1)$$

$$A(i) = \frac{NDVI(i) - Mean(NDVI)}{STD(NDVI)} \quad (2)$$

where IR is near-infrared band, R is infrared band. NDVI (i) is defined as the growing season NDVI (April to September) in a given year i; the mean (NDVI) and STD (NDVI) are the average value and the standard deviation of the NDVI, respectively. If $|A(i)| \leq 1$, then a moderate anomaly occurred; if $|A(i)| \geq 1$, then a large anomaly occurred; and if $|A(i)| \geq 2$, then an extreme anomaly occurred. Additionally, if $A(i) > 0$, then a positive anomaly occurred, and if $A(i) < 0$, then a negative anomaly occurred.

2.3.2 Detecting anthropogenic influence

We distinguished the NDVI linear trend between the climate change and human factors by actual and simulated NDVI. The simulated NDVI was acquired by liner regression from the actual NDVI and climate factors (temperature and precipitation) via total least square optimal regression; this method has been widely used in the attribution of human influence on climate in scientific researches (Gillett, 2002; Gillett et al., 2008; Stott et al., 2000). The human induced NDVI trend is the gap between actual NDVI and simulated NDVI.

2.3.3 Hurst exponent

The estimated Hurst exponent, which was invented by Harold Edwin Hurst in 1951, it is used to evaluate whether the long-term variation of a time series is continuous or random which is suitable for the trend analysis of future vegetation dynamics (He et al., 2011; Hurst, 1951; Miao et al., 2014a). Rescaled range analysis (R/S) is the oldest and best-known method to estimate the Hurst exponent (Peng et al., 2012). For details about how to calculate the Hurst Index, please refer to equation in Miao and Li's study (Li et al., 2013; Miao et al., 2014a). When the Hurst index (0-1) equals 0.5, then the time series is stochastic, or without consistency. A value greater than 0.5 but less than 1 indicates the long-term future sustainability of the time series. A value less than 0.5 indicates the anti-consistency (future anti-trend) of the time series, with lower values corresponding to greater sustainability of the anti-consistency (He et al., 2011; Li et al., 2013).

3. Results

3.1 Inter-annual variations in the growing season NDVI

3.1.1 At the regional level

Figure 2 indicates the linear variations in the growing season NDVI (from April to September) for the MP, for M and for IM during the period from 1982-2011. The average NDVI in IM (0.34-0.37) was a little higher than that in M (0.27-0.31). This result indicates that the vegetation in IM grows better than M. The magnitude of NDVI on the MP exhibited no obvious significant trend, in addition to M and IM. Combining the view of the three time series, we found a turning point after 2002 over the MP, as determined by the Mann–Kendall trend tests (Figure.3) for the period from 1982 to 2011. This turning point was primarily caused by the combined summer drought–dzud after 1999-2001. The consecutive summer drought–dzud was the worst of the last 50 years when 30% of the national herd perished, when 8.5 million livestock, 20% of the national herd, died during this period, with most of the drought happened in the western desert biome (Fernández-Giménez et al., 2012; John et al., 2013). Thus, this turning point of decreasing vegetation also existed in mainland China according to Peng’s study (Peng et al., 2011). The temporal NDVI value decreased rapidly, along with the extreme continuous drought, although vegetation recovered quickly after the drought. From 1982-2002, the time series of NDVI for MP, IM and M were enhanced at an average rate of $0.05\% \text{ yr}^{-1}$ ($P < 0.10$). From 2002-2011, the NDVI for MP, IM and M were enhanced at an average rate of 0.21%, 0.16% and 0.25 % yr^{-1} , respectively ($P < 0.10$).

3.1.2 At the biome level

The entire MP could generally be assigned to three biomes: desert, grassland and forest (Figure 1). Each biome displayed a remarkable regional difference in NDVI values between M and IM, with high spatial heterogeneities (Figure 4). The forest biome has a higher average NDVI value than the grassland biome, and the desert biome has the lowest NDVI value. The fluctuation in the vegetation NDVI (the proportion of average value and standard deviation) in M was larger than in IM, indicating that the terrestrial vegetation in IM is more stable. Figure 4 lists the NDVI variations for the three biomes; only the NDVI for the forest in IM implies an obvious trend ($0.06\% \text{ yr}^{-1}$) from 1982 to 2011 ($P < 0.05$). NDVI of forest was not really affected by the continuous 1999-2001 summer drought as it recovered quickly after 2002. This result may be attributed to afforestation and reforestation projects in the northern part of China, such as the Natural Forest Conservation Program, Three-North Shelterbelt Program, and the Grain for Green Project, which have been conducted since 1978 (Liu et al., 2008; McCarty, 2001).

3.2. Spatial patterns in growing season NDVI

3.2.1 At the regional level

Figure 5A and 5G lists the separate inter-annual percentages of greenness anomalies in IM and in M, which were calculated in all pixels across the three biomes, spanning from 1982-2011. Accordingly, areas with positive greenness anomalies ($A(i) > 0$) in IM increased at a rate of 0.0182 yr^{-1} ($R=0.62$, $P<0.01$), from 48% in 1982 to 73% in 1999 (Figure 5A), whereas positive greenness anomalies in M enhanced at a rate of 0.0176 yr^{-1} ($R=0.53$, $P<0.01$), from 48% to 61% at the interim (Figure. 5E). From the late 1990s to 2011, areas with positive anomalies in both IM and M showed no obvious trends (Figure 5A & 5E). In particular, the spatial anomaly fluctuation (the proportion of the average value and the standard deviation of the time series) in IM (3.35) was larger than in M (2.94) during recent decades.

3.2.2 At the biome level

Figure 4B-4D & 4F-4H show the inter-annual proportion of areas with six standardized anomalies across three biomes. We found that the positive greenness anomalies experienced high heterogeneity in biomes, with the slope of the forest NDVI ranking first ($R=0.50$, $P<0.01$), followed by the desert ($R=0.72$, $P<0.01$), and grassland displayed no obvious changing trend. Spatial trend of the greenness anomaly on the entire plateau from 1982 to 2011 is illustrated in Figure 6. There was a degradation trend in desert vegetation in the western part of the plateau, in the middle part of M and in *Xilin Gol* in IM, as indicated in yellow, orange and red. We concluded that the desert biome was more vulnerable than forest and grassland biomes during the last three decades. Our result was generally consistent with a previous study by Ranjeet et al. (2013), who suggested that the desert biome in MP was more vulnerable to drought than the grassland biome because of a low carbon sink capacity in the desert and a quick recovery in grasslands following summer droughts (John et al., 2013). Moreover, most of the IM, except *Xilin Gol* and northern M, represented a recovery trend, indicated in blue.

3.3 Vegetation response to climate and anthropogenic factor

Regional dynamics of vegetation coverage were usually determined by human activity and climate, particularly by overgrazing and by long-term changes in air temperature and in precipitation (Li and Yang, 2014; Piao et al., 2011; Xu et al., 2014). The time series of all factors in Figure 7 captures the actual trend of NDVI from 1982 to 2011. During the past three decades, NDVI variations induced by anthropogenic and climate factors exhibited an opposite trend over the MP, IM and M. No obvious statistically anthropogenic forcing NDVI trend was captured from 1982 to 2011. However, an approximately $0.17\% \text{ yr}^{-1}$ ($R=0.45$, $P=0.06$) rate of nature-induced NDVI enhancement

was observed before 1999 (1982-1999), and an obvious decreasing trend of $0.26\% \text{ yr}^{-1}$ ($R=0.62$, $P=0.10$) was observed after the year 1999 (1999-2006). The correlation coefficient of the actual NDVI with nature-induced NDVI was 0.38 ($P<0.05$) and was 0.23 ($P=0.21$) with the anthropogenic NDVI. We could conclude that natural forcing remained the main factor affecting the vegetation on the entire MP during the past 30 decades, although the contribution was relatively lower than expected due to the disturbance of human activities.

In Figure 8, we listed the anthropogenic-induced NDVI separated from the grassland to compare the difference in human activity strength between M and IM from 1982 to 2011, based on the method of the total least square optimal regression (Gillett et al., 2008; Stott et al., 2000). The magnitude of NDVI impacted by human elements in IM (0.16-0.23) was larger than that in M (0.004-0.12). IM has received widespread attention because of stress from a booming population, relatively higher economic development and general claims of overgrazing (Miao et al., 2014a). Since the late 1980s, the Chinese administration has had a tendency to maintain more animals on stock in the community unit (Sneath, 1998). We could see a slightly increase in the magnitude of the NDVI in IM from the late 1980s to 2000, whereas after 2000 (2000-2012), the negative impact reversed at a rate of $0.3\% \text{ yr}^{-1}$ ($R=0.70$, $P=0.01$) in IM. This result was consistent with Yan's study in 2011, where, after 2000, the grassland in IM reversed from degradation due to a variety of Chinese ecological projects (Wu et al., 2012; Yan et al., 2011). In terms of M, there were no significant changes, except in the year 2011.

3.4 Future vegetation changes

The future dynamics of the vegetation NDVI during the growing season were simulated in Figure 9 based on the Hurst exponent. The average Hurst values from 1982 to 2011 for IM and for M were 0.651 and 0.645, indicating that most of the regions will maintain a positive sustainable trend. The green-colored regions were the most sustainable areas (approximately 93%), suggesting that most of the vegetation coverage has a positive trend in the future. Only 6.5% of the plateau showed an inconsistency trend of future vegetation dynamics, and most of these regions are grassland and desert, with sparse vegetation, as indicated in purple (IM: 6.9%; M: 6.35%).

The Hurst value in Figure 9 predicted a positive recovery trend across most of the region, as indicated in green. A negative anti-sustainability trend was found in the central part, as indicated in purple (including *Hentiy*, *Suehaatar Southern Dornogovi*, *Dornod* and *Center* for M; *Baotou*, western *Xilin Gol*, *Hulun Buir* and *Ordos*, central *Hulun Buir* for IM). In this analysis, the inconsistency referred to the combined effect of human activities and climate-related changes, whereas high sustainability referred to the individual impacts of human activities or climate-related

changes. In terms of vegetation biomes, all Hurst values were larger than 0.5; forest had the highest Hurst value (MP: 0.666; IM: 0.654; M: 0.672), whereas desert (MP: 0.641; IM: 0.640; M: 0.642) and grassland had lower values (MP: 0.629; IM: 0.653; M: 0.598).

4. Discussion

Satellite-derived data were an effective resource to diagnose vegetation productivity (Fensholt and Proud, 2012). Due to the inconformity of different datasets, results vary and research claimed that NDVI maintained from 1998 to 2007 showed great variation in the IM based on the SPOT-VEGETATION data (Chuai et al., 2013). Using the MODIS dataset, studies noted that the vegetation in IM in 2010 grew better than that in 2000 and NDVI coverage of Mongolia showed a lightly improved trend from 2001 to 2010 (Mu et al., 2013; Wang and Li, 2011; Zhang et al., 2012). In this study, we chose a dataset with a relatively long time series in the past three decades-GIMMS/AVHRR NDVI3g, the dataset was particularly effective in this region (Miao et al., 2013a), providing the longest-term series of global and regional vegetation history. From Figure 6, this finding suggests that in a period, based on the analyses of recent trends (and rates) of vegetation degradation in M, we speculate the following: grassland may reverse from its continuous increasing trend; desert vegetation may continue decreasing; and only the forest will have an enhanced trend in the future. The government and local communities should be aware of future grassland degradation and develop appropriate responses which manage the social and environmental factors.

This paper demonstrated an enhanced trend of forest NDVI in IM at a rate of $0.06\% \text{ yr}^{-1}$, this observation was because the government in IM has created large ecological projects, such as the “Natural Forest Conservation Program” and the “Grain for Green Project”, since 1978. The projects not only improved the vegetation coverage and quality (Liu et al., 2013; Miao et al., 2013b) but also soil erosion was reduced and carbon sequestration was significantly enhanced after the projects although some problematic impact on the livelihoods of local communities, as indicated by the most recent studies (Deng et al., 2013; Liu et al., 2008). Meanwhile, monitoring the vegetation growth was more urgent in M because Zhen found that Mongolian herders relied more heavily on livestock for meeting their consumption needs than herders in IM (Zhen et al., 2010b) and that there was no state law protecting the grassland in M. In general, China had better access to solutions to manage the sudden extreme weather and may show a demonstration effect in grassland management to the Mongolian context.

An increased area experiencing vegetation recovery in the future was forecasted on the plateau, especially the forest. Our result is inconsistent with previous study that the changing climate could enforce the spread of grasslands which are presently occupied by forest on MP (Dulamsuren and

Hauck, 2008). A previous study indicated that increased temperature decreases the sensitivity of plant growth (Piao et al., 2006), and the IPCC report claimed that global temperatures will continue increasing at a faster rate than before. We anticipate that perhaps our human efforts for natural recovery will be part of the reason for improvements in vegetation productivity. Since a number of international institutes have put great effort into better managing the pastoral communities and culture in the plateau; examples of special agencies from different countries include the “Swiss Agency for Development and Cooperation in Mongolia”, the “Mongolia and Inner Asia Studies Unit in Cambridge”, and “The University of Central Asia's Mountain Societies Research Centre (MSRC)”. More combined cooperation should be joined to improve the ecological and continued sustainability of pastoralism on the MP.

5. Conclusions

In this study, we analyzed the spatial and temporal vegetation trends on the Mongolian Plateau and its influencing factors from 1982 to 2011 across the dominant biomes (desert, grassland and forest) based on a 30-year satellite-derived NDVI dataset. The presented initial results demonstrated that vegetation NDVI trends differ in different biomes, regions and periods. There was an increase in the vegetation NDVI at a rate of $0.05\% \text{ yr}^{-1}$ on the MP from 1982 to 2002 and an accelerated enhanced rate of $0.21\% \text{ yr}^{-1}$ from 2002 to 2011, accompanied by an increase in the desert biome on the MP and by an increase in the forest biome in IM. Regarding spatial patterns, vegetation areas with positive anomalies were found in IM (0.0182 yr^{-1}) and in M (0.0176 yr^{-1}). Vegetation biomes, particularly the desert biome, were extremely sensitive to climate change. From our analysis, human activities do not show a significant signal as it is quite weaker than climate change at regional scale although it shows strong influence as some local sites. The further analysis of anthropogenic forcing effects on vegetation changes via higher accuracy in regional areas and the quantification of the relative roles of these factors under different national policies and land use intensities are of scientific and social importance.

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Captions:

Figure 1. Location map of the study area (including national boundaries Russia, Mongolia and China; Ecological zonings: Desert, Grassland and Forest)

Figure 2. Inter-annual averaged growing season NDVI from 1982 to 2011 of MP, IM and M

Figure 3. Statically value of the MK test for the NDVI dynamics from 1982 to 2011 of MP, IM and M

Figure 4. Inter-annual averaged growing season NDVI for desert, grassland and forest from 1982 to 2011

Figure 5. Inter-annual variation in the percentage of greenness anomaly areas in all biomes, i.e., desert, grassland and forest

Figure 6. Slope of the greenness anomaly from 1982 to 2011 at the 90% significance level

Figure 7. Inter-annual NDVI for all forcings, anthropogenic forcing and natural forcing on the MP, IM and M

Figure 8. Inter-annual anthropogenic NDVI of grassland in IM (black solid line) and in M (blue solid line)

Figure 9. Spatial distribution of the Hurst exponent on the MP; The value can be divided into the 11 following intervals: -5 ($0 \leq H \leq 0.20$); -4 ($0.20 \leq H \leq 0.25$); -3 ($0.25 \leq H \leq 0.35$); -2 ($0.35 \leq H \leq 0.45$); -1

($0.45 \leq H < 0.50$); 1 ($0.50 < H \leq 0.55$); 2 ($0.55 \leq H \leq 0.65$); 3 ($0.65 \leq H \leq 0.75$); 4 ($0.75 \leq H \leq 0.85$); and 5 ($0.85 \leq H \leq 1.00$), green denotes positive trends

Table.1 The slope of inter-annual averaged growing season NDVI for different biomes for different periods of MP, IM and M

NDVI	Trend from 1982 to 2011			Trend before 2002			Trend after 2002		
	MP	IM	M	MP	IM	M	MP	IM	M
Whole	0.0001	0.0000	0.0001	0.0005	0.0005	0.0005	0.0021	0.0016	0.0025
Desert	0.0000	0.0000	0.0000	0.0003	0.0003	0.0003	0.0001	0.0003	0.0000
Grassland	-0.0001	-0.0002	0.0002	0.0004	0.0003	0.0005	0.0032	0.0010	0.0061
Forest	0.0003	0.0006	0.0002	0.0010	0.0014	0.0008	0.0046	0.0052	0.0042

Figure

Figure 1

Figure 2

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