Response of Vegetation to Climate Change in the Drylands of East Asia

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Abstract. Over the past 25 years, global climate and environmental changes have caused an unprecedented rate of vegetation change, as exemplified in the drylands of East Asia. In this study, we investigated the spatio-temporal changes of vegetation in this region and analysed their relationship with climate data. Our results show that vegetation productivity significantly increased from 1982 to 2006. This increasing trend was observed for most of the region, particularly for northwest Mongolia and central Inner Mongolia. Grasslands, croplands, forests, and shrublands, all exhibited this trend. The annual growth rate of the grasslands determined using the Normalized Difference Vegetation Index (NDVI) was the largest observed change; reaching 0.07% p.a, followed by shrublands (0.06%), croplands (0.03%), and forests (0.02%). In the different geographic regions, the roles of temperature and precipitation on vegetation growth were shown to be different. Temperature was the dominant factor for the observed NDVI increase in northwest Mongolia and the centre of Inner Mongolia. The combined influences of temperature and precipitation changes have resulted in the promotion of vegetation growth, as seen in eastern Gansu. Temperature change is the primary factor for initiating vegetation growth in spring and autumn because warmer temperatures increase the length of the growing season, and are thus evaluated as an increased NDVI value. Increased precipitation has been shown to play a positive role on vegetation growth during summer.

1. Introduction
Climate change in the drylands of East Asia has been expressed as a warming trend [1] and decreasing precipitation [2, 3]. Previous studies in this region have indicated an increasing number of extreme climate events such as drought, dust and sand storms, as well as severe winter storms [4]. Climate change affects the ecological and physiological features of natural systems but also those of anthropocentric systems [1, 5]. Vegetation links soil, the atmosphere, and water and serves as an “indicator” in global climate change research [6]. Monitoring changes in vegetation growth and understanding their causes plays a crucial role in global climate change research [7].

In recent years, scholars have researched vegetation changes and their relationship with climate change using NDVI data. For example, Ichii [8] observed a significant positive correlation between annual NDVI and temperature in the northern mid-to-high latitude areas between spring and autumn. Park and Sohn examined the vegetation variations across East Asia from 1982 to 2006 using NDVI data, and recognized a pronounced positive trend prior to the mid-1990s (1982–1996) and a negative trend after the mid-1990s (1997–2006) [9]. They concluded that increased temperature was the main
reason for the promoted vegetation productivity that they observed. Similarly, Song and Ma found that
temperature has a significant positive influence on vegetation growth in China, while in arid and semi-
arid regions precipitation is the most important climatic factor [10].

The objective of this study is to improve the understanding of vegetation changes and their
relationship with the climate in the drylands of East Asia by analysing data from 1982–2006. To
achieve this goal, we first analysed the spatio-temporal trend of vegetation NDVI and then analysed
the correlation between NDVI and climate data (temperature and precipitation) for different vegetation
types. Our study provides important insight into understanding climate change, furthering research on
ecosystem evolution.

2. Data and Methods

2.1. Study Area
The East Asian drylands encompass Mongolia and three provinces in northwest China: the Inner
Mongolian Autonomous Region, Ningxia Hui Autonomous Region, and GanSu Province (Figure 1).
Precipitation and temperature vary considerably from west to east and from north to south in this
region [4]. Grasslands are the dominant vegetation type, accounting for 52.42% (Figure 1), followed
by cropland, forest, shrubland, and savanna.

![Figure 1. Distribution of vegetation types in the drylands of East Asia.](image)

2.2. Data
Advanced Very High Resolution Radiometer (AVHRR) NDVI data were collected with a spatial
resolution of 8 km × 8 km, taken at 15-day intervals from 1982 to 2006, these data were obtained from
the Global Inventory Monitoring and Modelling Studies (GIMMS) group. AVHRR NDVI uses the
maximum value compositing procedure to minimize the effects of cloud contamination, varying solar
zenith angles, and surface topography [11]. Temperature and precipitation data were obtained from the
Modern Era Retrospective-Analysis for Research and Applications (MERRA). We performed
reanalysis of the data set at a spatial resolution of 0.5 ° × 0.667 °. The land coverage map (MCD12Q1)
was derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data using the
International Geosphere-Biosphere Programme (IGBP) classification scheme [12]. The spatial
resolution is 500 m. We identified the vegetation type for each pixel using a MCD12Q1 map of our
study area.

2.3. Methods
First, we calculated the mean of annual and seasonal NDVI per vegetation type. We then analysed
the trend of NDVI with climatic factors using a linear regression method and then analysed the revealed
relationships for each of the different vegetation types.

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3. Results and Discussion

3.1. Trends of NDVI with Climate Data

Figure 2 shows the geographical distribution of mean NDVI from 1982 to 2006. NDVIs vary from 0.1 to 0.6 across the vegetation areas. In northern Mongolia, Inner Mongolia and southern GanSu, the NDVIs are the largest, reaching 0.50 and the principal land cover type is forest (Figure 1). NDVI variations from 0.3 to 0.4 are typically cropland, which is sporadically distributed within the centre of Mongolia, northern Inner Mongolia and southern GanSu. The rest of the study area is grassland, which has an NDVI from 0.1 to 0.3.

Figure 2. The spatial distribution of annual mean NDVI across the study area per vegetation type.

The temperature of the East Asian drylands showed an increasing trend in most areas from 1982 to 2006 (Figure 3a). The regions showing significant increases in temperature are mainly distributed in the northwest of Mongolia, with an increase rate as high as 0.15 °C p.a. The trend of annual precipitation is more complex and differs in the varying geographic regions (Figure 3b). In the north of the drylands, the annual precipitation exhibited an extremely decreasing precipitation trend. The rate of decrease for precipitation in northern Mongolia was as high as 10 mm p.a. However, in the south of the drylands the annual precipitation showed an increasing trend, especially in the southeast of GanSu, and the rate of increase for precipitation was also as high as 10 mm p.a.

Figure 3. The spatial distribution of the annual average temperature change (a) and annual average precipitation rate (b) in the drylands of East Asia during 1982–2006.

We analysed the interannual trend of average regional NDVIs (Figure 4a) and their spatial distribution (Figure 4b) within the study area. For all regions, the annual average NDVI showed a significant increase (0.06% p.a., p < 0.05), indicating increased vegetation productivity. This is generally consistent with the findings that vegetation productivity in the northern middle latitudes had been increasing over the last two decades [13-15]. NDVI jumped from a minimum in 1992 to a maximum in 1994. Before 1993, NDVIs exhibited a significantly increasing trend at rate of 0.06 % p.a. After 1994, NDVIs showed a reduced increasing trend of 0.03 % p.a. Annual NDVIs revealed an increasing trend for all vegetation types (Table 1) and the annual NDVI increase rate was 0.07 % p.a. for grasslands and 0.06% for shrubland.
The average NDVI increased over 66.79% of the study area (Figure 4b), particularly over northwestern Mongolia, central Inner Mongolia, central NingXia, and eastern GanSu. In these four regions, the increased trend of NDVI exceeds 0.003 p.a. The increased annual NDVI seems to be related with climate (Figure3a Figure3b); nevertheless, the rising atmospheric CO2 concentration [16] and anthropogenic activities such as land management and afforestation [17] may also play a role. Although decreasing trends in precipitation were observed in northwestern Mongolia and in central Inner Mongolia (Figure 3b), NDVI in this region continues to increase. This may be related to increased temperature that results in the lengthening of growing season, which is the main reason for NDVI increase. Zhang and Yan’s studies showed NDVI increase is mainly caused by temperature in Inner Mongolia [19, 20]. Yan and Zhang also concluded that the enhancement effect of warmer temperatures and CO2 enrichment partly offsets the negative effect of decreasing precipitation in the central Inner Mongolian steppe [19]. Eastern GanSu experienced a warming trend (Figure 3a) and an increasing trend of precipitation at a rate of > 8 mm p.a. (Figure 3b). Increased temperature and precipitation promotes the vegetation growth in this region.

In contrast, NDVI showed decreasing trend in eastern Mongolia, the northeast of Inner Mongolian, and southern Ningxia. Significant decreases in NDVI account for 3.61 % of the total study area. The decreased NDVI in eastern Mongolia and the north-eastern Inner Mongolian may be associated with decreased precipitation (Figure 3b). Park and Sohn’s [9] study also showed that significantly reduced precipitation contributes to reduced vegetation activity in eastern Mongolia. Decreased temperature may be the main reason for NDVI decrease in southern Ningxia (Figure 3a).

**Figure 4.** The trend of regional average NDVI (a) and spatial distribution of annual NDVI (b) in the drylands of East Asia during 1982–2006.

We analysed the seasonal trends of NDVI from 1982 to 2006. Vegetation NDVIs showed an increasing trend over all four seasons with the weakest increasing trend in summer (0.01% p.a.). The vegetation NDVIs displays a significant increasing trend for spring and autumn (Table 1). Rising spring and autumn temperatures increases the length of the growing season, which increases vegetation productivity in spring and autumn [7]. We also examined the seasonal trend of NDVIs for grassland, cropland, forest, and shrubland. In spring and autumn, NDVIs showed an upward trend for the four vegetation types and summer and winter, the forest NDVI shows a decreasing trend that differs from other vegetation types.

**Table 1.** The trend of NDVI.

| NDVI type   | annual | spring | summer | autumn | winter |
|-------------|--------|--------|--------|--------|--------|
| Vegetation  | 0.06%**| 0.11%**| 0.01%  | 0.08%* | 0.07%  |
| Grassland   | 0.07%**| 0.12%**| 0.02%  | 0.08%* | 0.09%* |
| Cropland    | 0.03%  | 0.08%  | 0.02%  | 0.09%* | 0.02%  |
| Forest      | 0.02%  | 0.06%  | -0.07% | 0.09%  | -0.05% |
| Shrubland   | 0.06%**| 0.06%* | 0.09%  | 0.07%* | 0.05%* |
3.2. Climate Impacts on Vegetation Change

Annual NDVIs of the different vegetation types show a significantly positive correlation with temperature (Table 2). However, the correlation of NDVI and precipitation was weak. For the different vegetation types, annual NDVI was significantly correlated with temperature except for forest, which displays a markedly negative correlation with precipitation. Overall, temperature plays the dominant role on NDVI increases for the different vegetation types.

At the seasonal scale, in spring, all vegetation types exhibited a significantly positive correlation between NDVI and temperature. Over time increased temperature prolongs the growing season which is the main reason for the expressed NDVI increase for the different vegetation types [20]. NDVI was not shown to be strongly associated with precipitation except for forested areas. Forest NDVIs showed the best correlation with temperature and precipitation relative to the other vegetation types. Spring precipitation may reduce surface temperatures hindering forest growth.

In summer, for all vegetation types, the correlation of NDVI and precipitation was better than temperature. Precipitation was the primary influence on the change of vegetation NDVI [20]. The response to the climate of the different vegetation types was different, particularly for grassland, which displayed a negative relationship with temperature, yet showed a positive correlation with precipitation. In grasslands, high temperatures promote water evaporation and induce a soil moisture deficit, which is not conducive to the growth of grass. Forest NDVIs exhibited the best correlation with temperature, as with precipitation. However, excessive summer precipitation reduced the forest NDVI (Table 2).

In autumn, each vegetation type is significantly correlated with temperature, but no better than in spring. Rising temperatures prolong the growing season and this is the main reason for the observed NDVI increase for four of the vegetation types. The correlation between NDVI and precipitation was significant for each vegetation type except for croplands in autumn. Compared to the other three seasons, the relationship between NDVI and precipitation was the greatest for each vegetation type in autumn.

### Table 2. The correlations of NDVI and temperature/precipitation and its significance

| R       | NDVI-temperature | NDVI-precipitation |
|---------|-------------------|--------------------|
|         | annual | spring | summer | autumn | winter | annual | spring | summer | autumn | winter |
| vegetation | 0.55** | 0.68** | -0.09  | 0.56** | -0.07  | -0.25  | 0.06   | 0.26   | -0.39  | -0.28  |
| grassland | 0.46*  | 0.60** | -0.16  | 0.50   | 0.00   | 0.17   | 0.09   | 0.28   | -0.43* | -0.36  |
| cropland  | 0.43*  | 0.65** | 0.11   | 0.48   | -0.11  | -0.18  | -0.07  | 0.08   | -0.11  | 0.02   |
| forest    | 0.22   | 0.72** | 0.50   | 0.40   | -0.38  | -0.48  | -0.50  | -0.38  | -0.45* | 0.04   |
| shrublands| 0.50*  | 0.68** | 0.29   | 0.61** | -0.21  | -0.19  | 0.05   | 0.09   | -0.53** | -0.1   |

Note: ** significance at p<0.01 level, * significance at p<0.05 level.

4. Conclusion

We examined the trend of vegetation change and its relationship with climate data in the drylands of East Asia from 1982 to 2006 using AVHRR NDVI data. Vegetation growth has apparently improved over the 25 year period with an annual NDVI increase of 0.06 % (p < 0.05). The trend of NDVIs was different for the different geographic regions in the study. Significantly increasing trends were observed in the northwest of Mongolia and central Inner Mongolia. Temperature was interpreted to be the primary factor affecting vegetation productivity in the northwest of Mongolia and central Inner Mongolia. Increased temperature and precipitation together promoted vegetation grown in eastern GanSu. Some areas also show decreasing trends, for instance, eastern Mongolia and northeastern Inner Mongolia, to which the decreased NDVIs in the areas are attributed. Vegetation NDVI exhibited upward trends in different seasons, while the trend was statistically significant in spring and autumn. All vegetation types showed increasing trends except for forests in summer and winter.
Temperature is the dominant climatic factor responsible for the increasing NDVIs in the study area. Annual vegetation NDVIs showed a significant correlation with temperature. Seasonally, NDVIs are significantly correlated with temperature in spring and autumn. The rising temperatures in spring and autumn increased the length of the growing seasons, accelerating NDVI increase. The correlation between NDVI and precipitation was not found to be significant. The vegetation NDVIs showed a positive correlation with precipitation in summer. In arid and semi-arid regions, summer precipitation contributes to vegetation growth. The data from this study have leads us to conclude that different vegetation types respond to the elements of climate change differently. For example, in summer, grasslands show a negative correlation between NDVI and temperature, which was opposite to the other vegetation types. Forest was different from all the other vegetation types as well, showing a negative relationship with precipitation in summer.

Acknowledgements
The study was supported by the Director Innovation Foundation of the Center for Earth Observation and Digital Earth, Chinese Academy of Sciences (Grant No. Y2ZZ19101B).

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