Basic and Applied Dryland Research 1, 2 (2007), 138-154
© Arbeitskreis Wüstenökologie, Gesellschaft für Ökologie
http://www.badr-online.de
ISSN 1864-3191

Remote Sensing based study on intra-annual dynamics of vegetation and climate in drylands of Kazakhstan

P. A. Propastin [a], **M. Kappas** [a], **S. Erasmi** [a] **and N. R. Muratova** [b]

[a] *Department of Geography, Georg-August University Göttingen, Goldschmidtstr. 5, 37077, Göttingen, Germany*
Email: ppropas@uni-goettingen.de

[b] *Laboratory of Remote Sensing and Image Analysis, Kazakh Academy of Science, Shevchenko Street 15, 480040, Almaty, Kazakhstan*
Email: nmuratova@hotmail.com

Received 17 April 2007; original version accepted 25 June 2007

Abstract

We combined Normalized Difference Vegetation Index (NDVI) datasets derived from the Advanced Very High Resolution Radiometer (AVHRR) and climate records to analyse within-season temporal relationships between vegetation activity and two eco-climatic parameters (precipitation and temperature) in an arid region of Central Kazakhstan. Assessments of these relationships were performed by calculating correlation coefficients between 10-day values of NDVI and the both climatic parameters throughout the growing season (April-October). The correlations were calculated for every pixel as well as for the aggregated datasets representing different land cover types and the entire study area. The results indicate that strong significant positive correlations exist between NDVI and each of the explanatory climatic parameters at all spatial scales. Temperature was considered to be the leading climatic factor controlling intra-annual NDVI dynamics. The correlation coefficients between NDVI-rainfall and NDVI-temperature exhibit a clear structure in terms of spatial distribution. The results indicate that the response of vegetation to climatic factors increases in order from shrubs and desert vegetation to semi-desert, short grassland and to steppe vegetation.

Keywords: NDVI, climate, vegetation response, time lag, correlation analysis.

Zusammenfassung

Die Arbeit untersucht zeitliche Zusammenhänge zwischen Vegetationsdynamik und Dynamik von Klimaelementen (Temperatur und Niederschlag) in einem Trockengebiet des Zentral-Kasachstans. Die Datengrundlagen der Arbeit umfassten den Normalized Difference Vegetation Index (NDVI) von dem Advanced Very High Resolution Radiometer

(AVHRR) sowie Messwerten der Klimastationen für Niederschlag und Temperatur. Die Schätzung der Stärke des Zusammenhanges erfolgte durch Berechnung des Koeffizienten der Korrelation und Kreuzkorrelation zwischen den Zeitreihen der Dekadenwerte des NDVI und der beiden Klimaelemente während der Pflanzenwachstumsperiode. Die statistischen Zusammenhänge wurden auf verschiedenen Skalen räumlicher Generalisierung betrachtet: von dem gesamten Gebiet bis zu einzelnem Pixel. Die Ergebnisse beweisen, dass auf allen Betrachtungsskalen strenge Interrelationen zwischen der Dynamik des NDVI auf einer Seite und den beiden Klimaelementen auf der anderen Seite bestehen. Temperatur erwies sich als der Hauptfaktor für die Kontrolle der Vegetationsdynamik durch das Klima. Die räumliche Verbreitung der Werte des Korrelationskoeffizienten zeigte ein deutliches Muster. Dieses Muster spiegelt die Unterschiede zwischen einzelnen Vegetationstypen in bezug auf ihre Reaktionskraft und Reaktionsgeschwindigkeit zu der Einwirkung der Klimaelemente wider.

Schlüsselbegriffe: NDVI, Klimaelemente, Vegetationsreaktion, Zeitverschiebung der Vegetationsreaktion, Korrelationsanalyse.

Introduction

There is a great demand for a better understanding of the nature of climate impacts on drylands as a whole system and on the vegetation cover of drylands as an important component of this ecosystem at all scales from global to regional and local. This understanding requires detailed investigations on the vegetation response to climate factors. On the one hand, knowledge of this response holds the potential for discrimination of threatened areas and forecasting of damage grade by drought events. On the other hand, this knowledge subsequently improves planning of protection arrangements. Another benefit is associated with forecasting of regional agricultural yields for drought years, which improves planning for food supply for times of food scarcity (Gisladottir & Stocking, 2005).

Satellite derived Normalized Difference Vegetation Index (NDVI) is a very convenient tool for monitoring terrestrial ecosystems at all scales from global to local. It enables regular detection of seasonal and inter-annual changes in vegetation activity. The correlation between NDVI and aboveground biomass is well established. The satellite derived NDVI can serve as a general surrogate for vegetation conditions (Tucker et al., 1985). The vegetation absorbs a great part of incoming radiation in the visible portion of the spectrum (VIS=380-730 nm) and reaches maximum reflectance in the near-infrared channel (NIR=730-1100 nm). The NDVI, defined as ratio (NIR-VIS)/(NIR+VIS), represents the absorption of photosynthetic active radiation and hence is a measurement of the photosynthetic capacity of the canopy. Negative NDVI values indicate non-vegetated areas such as snow, ice, and water. Positive NDVI values indicate green, vegetated surfaces, and higher values indicate increase in green vegetation. The NDVI is established to be highly correlated to green-leaf density, absorbed fraction of photosynthetically active radiation and above-ground biomass and can be viewed as a surrogate for photosynthetic capacity (Tucker & Sellers, 1986). Since the early 1980th many studies of vegetation distribution and vegetation conditions at both global and regional scales were based on the use of time-series data of the Advanced Very High Resolution Radiometer (AVHRR) sensor launched by the National Oceanic and Atmospheric Agency (NOAA). AVHRR derived NDVI data have been successfully used for monitoring vegetation activity and environmental changes at regional and global scales (Kowabata et al., 2001; Tucker et al., 2001; Xiao & Moody, 2004; Tateishi & Ebata, 2004), detection of droughts (Kogan, 1997), desertification and land degradation studies (Budde et al., 2004; Evans & Geerken, 2004).

The investigation of the relations between vegetation pattern and its explanatory factors, particularly climate and human impact, is an object of applications of NDVI. Temporal and spatial correlations between NDVI and climatic factors are investigated in many research works. Particularly good correlation in the arid regions, both spatially and temporally, is documented based on NDVI and rainfall (Richard & Poccard, 1998; Yang et al., 1998; Li et al., 2002; Wang et al., 2003). The relationship between NDVI and temperature is reported to be also significant. Yang et al. (1998) and Wang et al. (2003) reported about a lower influence of temperature on NDVI. On the contrary, Li et al. (2002) and Xiao & Moody (2004) proved a higher impact of temperature on within-season and inter-annual NDVI. The response of NDVI to rainfall and temperature depends on vegetation types and varies by geographical region (Nicholson & Farrar, 1994; Shultz & Halpert, 1995). Woodland and forest vegetation shows a lower correlation between NDVI and climate factors. Shrubs and desert vegetation patterns are reported to be strongly correlated with temporal and spatial variations of climate factors. Vegetation patterns in steppe grassland and savannah reveal the highest correlation with rainfall and temperature (Li et al., 2002; Wang et al., 2003; Li et al., 2004).

The goal of the study is to analyse the seasonal variations of vegetation activity in a semi-arid region in the central part of Kazakhstan (region Northern Balchash) and to explore their relationships with corresponding variations in rainfall and temperature. Our research is based on NDVI data that have been retrieved from Advanced Very High Resolution Radiometer (AVHRR) and a gridded climatology dataset calculated from the records of climate stations from the study area.

Study area

The study area is located in the middle part of Kazakhstan between 46 and 50° northern latitude and 72° and 75° eastern longitude. The climate of the region is dry, cold and high continental. Average annual precipitation is above 250-300 mm per year in the north of the study area, and below 150 mm in the south. The most part of precipitation falls during warm period from March to October. The temperature amplitude is relative high: average January temperature is below –12° C and average July temperature is about 26-28° C.

The south of the study region is vegetated by sagebrush and perennial saltwort associations. Dominating vegetation species here are *Artemisia terrae-albae, Artemisia pauciflora, Anabasis salsa, Salsola orientalis.* The northern section of the study region is occupied by steppe vegetation, where dominate short grassland species such as *Festuca sulcata, Stipa capillata* and *Stipa lessingiana*. The semi-desert vegetation complex occupying the mid of the study area represents a complex combination of real steppe turf grasses and semi-shrubs with halophytes (see Fig. 1).

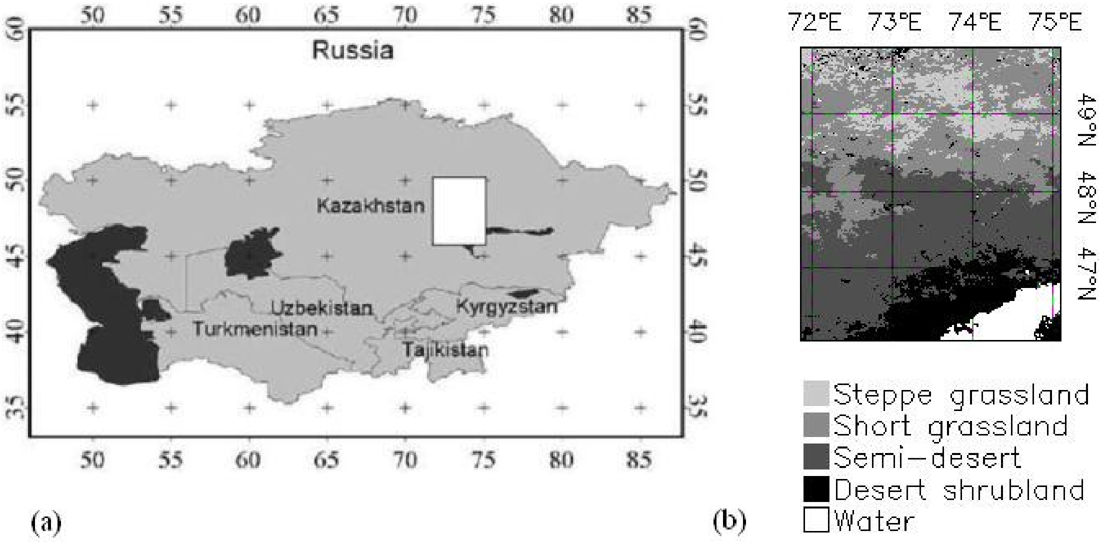

***Figure 1**: (a) Location of the study area on the map of Central Asia. (b) Map of vegetation types in the study area*

Data used in the study

NOAA AVHRR NDVI dataset

We used 10-day maximum NDVI composites of the AVHRR sensor with a spatial resolution of 8 km. The data cover the period of growing season (April-October) from 1985 to 2000. Data were derived from NASA´s Distributed Active Archive Center. Using a method described by (Los, 1993), NDVI data were calibrated against three time invariant desert targets located in the Big Arabian Desert, Nubia Desert and Taklamakan Desert. This method removes effects of sensor degradation and corrects drift between different sensor systems. In addition to that, we removed noisy pixel areas characterized by exceptionally low NDVI values relatively to their pixel neighbourhood. This pixels represented large cloud areas and were replaced by a mean value calculated from the temporal neighbouring NDVI layers.

Precipitation and temperature data

The climate data used in the study consist of 10-day rainfall and air temperature data collected and calculated by the National Hydrometeorological Centre of Kazakhstan (NHMCK) for 9 climate stations placed in the study area for the period April-October 1985-2001. The 10-day climate records were averaged to mean 10-day values over the study period, corresponding to the 10-day periods of the NDVI data, and then interpolated into raster maps based on the longitude, latitude and elevation of the weather stations. All raster maps of precipitation and temperature for the study area were constructed using an interpolation method known as kriging with an external drift.

To assess the accuracy of this data preparation, we randomly reserved 3 weather stations from the interpolation for one of the 10-day and compared interpolated and recorded values. Average error was less than 6%. It means that the interpolation approach worked effectively.

Analysis methods

We examined temporal relationship between NDVI and climate factors, precipitation and temperature by calculation correlation coefficients with these variables. Significance at the 5% confidence level was used as the test criteria for all correlation calculations. Analyses utilized time series of 10-day data throughout the growing season (April-October). Recent literature reports about the presence of a time lag between dynamics of climate factors, particularly precipitation, and the reaction of vegetation to this dynamics. The time interval can vary from 1 to 12 weeks depending on vegetation type (Richard & Poccard, 1998; Yang et al, 1998; Wang et al, 2003; Li et al, 2002). Therefore, in this study calculations were done both at the concurrently basis (correlation coefficients were calculated between the time-series of NDVI and precipitation over the same period) and by imposing time lag into the correlation analysis. In order to account for time lag, we calculated NDVI-climate correlation coefficients using time lags of 1 to 9 10-day units.

Most of the recent studies on investigation relationship between climate and vegetation dynamics have been based on the use of the data that are spatially aggregated over a defined geographical region or over any individual land cover/vegetation type. This way of data analysis is simpler than the analysis of relationships at per-pixel level but the use of the aggregated data can hides spatial patterns of the variables to be analysed and may not reflect the real situation at localities. Therefore, an analysis of relationships at sub-regional scale is more appropriate by the use of per-pixel information (Ji et al., 2004; Foody, 2003).

However, an interpretation of the analysis results derived at the level of a defined entire geographical space or at the level of any individual vegetation type is rather lighter than that derived for each pixel, particularly in the case if one needs only a general view of the relationship to be analysed.

We were more interested in the results presenting an universal behaviour of the vegetation of individual vegetation types spreading in the study region in the terms of their response to climatic parameters. But we also proved how significant are variations of this behaviour within each vegetation type. The spatial resolution of the NDVI and climate data (8 km) enabled us to look into local circumstances of the relationships between vegetation and climate dynamics. Hence, in the terms of the analysis scale we obtained results at three different spatial scales: averaged over the entire region, spatially averaged over each individual vegetation type, and for each pixel (per-pixel scale).

Spatial distribution of NDVI and climatic factors in the study area

There are two factors influencing the spatial patterns of vegetation and climatic variables in the study area: the south-north direction and the altitude gradient. Generally, the spatial variance of NDVI and both climatic variables are strongly predicted by the south-north factor, but the relief conditions slightly deform this rule and make the spatial patterns more difficult. Vegetation and rainfall variable display similar spatial patterns. Average precipitation increased markedly from south to north: from about 100 mm in the desert to over 280 mm in the steppe zone (Figure 2). The 10-year average of NDVI ranges from less than 0.05 in the southern area of the study region to more than 0.30 in the steppe zone. These are typical values for dominant xerophytic formations. Values lower than 0.05 in the southern area indicate areas with no photosynthetic activity. These are non-vegetated desert surfaces or solonchaks. Rare little forested islands in the steppe show NDVI values over 0.35. They are placed at altitudes above 800 meter and manifest a presence of vertical zonality in the study region. Average seasonal temperature generally decreased from south to north. In the south of the study region the temperature achieves 16-17 °C and the northern area is about 3-5°C cooler (see Fig. 2).

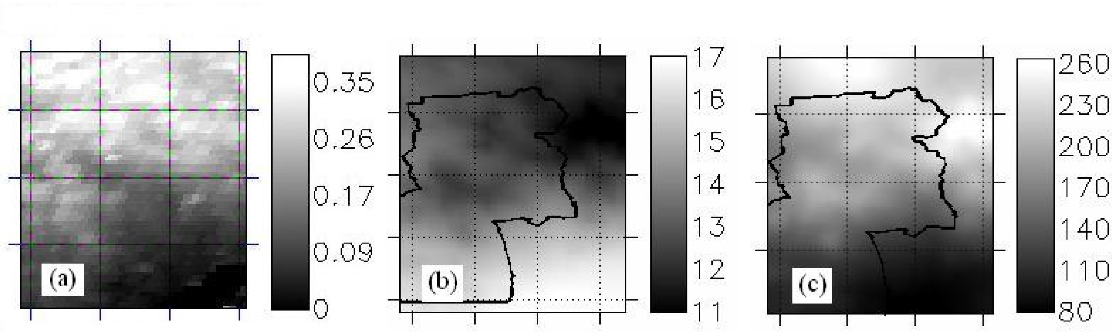

***Figure 2**: (a) Mean growing season NDVI calculated from the average of 8-km NOAA AVHRR for the period 1985-2001. (b) Mean growing season temperature, °C. (c) Regionalized total precipitation amount throughout the growing season, the graph presents an average over the period 1985-2004*

Results

Average characteristics of NDVI

The three major types of vegetation cover in the study area are strongly distinguished by different values of NDVI (Table 1). Steppe grassland records the highest average NDVI values for growing season (0.26), followed by the semi-desert vegetation (0.15). The desert vegetation displays the lowest values (0.11). Observing the seasonal averages NDVI values displays other results. The highest values in spring are associated with the desert vegetation, NDVI = 0.13. On the contrary, the short grassland of steppe regions shows the lowest value, NDVI = 0.07. For summer and autumn averages, distribution of NDVI values between the vegetation types is similar to that described for the whole growing season, the NDVI value decreases from the short grassland, to semi-desert short grassland/shrub, and to desert shrubland. NDVI values computed for the different vegetation types are reasonable close to corresponding vegetation in other studies performed in the central Kazakhstan. These regions also showed ordinal consistency, with short grass regions highest NDVI, grass/shrub regions second highest and shrubby desert regions lowest, in agreement with values in this study (see Table 1).

***Table 1**: Averaged characteristics of NDVI values for various vegetation types*

Vegetation type	**Average NDVI over 1985-2001**			
	Spring	Summer	Autumn	Growing season
Steppe	0.07	0.30	0.16	0.26
Short grassland	0.09	0.24	0.13	0.20
Semi-desert	0.11	0.17	0.11	0.15
Desert	0.13	0.07	0.07	0.11
Area-average	0.09	0.19	0.12	0.16

Temporal behaviour of climatic factors and vegetation within the growing season

Figure 3 illustrates the within-season cycles of NDVI and climate factors averaged over the entire study region. 16-year average of 10-day NDVI values (1985-2001) increased rapidly during spring (early April-mid-May), peaked during the summer months (mid-May-early July), and decreased during August-September-October. Precipitation showed two peaks, increasing from early April to early June and peaking in late May-early June. After that a slight decrease follows showing again an increase till the next peak in mid-July. Minimum of precipitation occurs in August-September. The duration of the growing season is approximately from April to October. The growth of vegetation begins between the second and the third decade of April; approximately 1 decade after temperature value has risen above zero. The curve of temperature displays a very symmetric form with a peak value in mid-July-early August. Generally, temperature rises during the months April-July, and then gradually decreases during August-October.

Figure 4 shows the growing season evolution of 10-day rainfall, temperature and NDVI for every pixel in the study region. These illustrations performed in form of hovmoller's diagrams (time-latitude) provide a general overview of the dynamic of the climate parameters. The temporal pattern in temperature seems to be similar throughout the study area. On the contrary, the pattern in rainfall varies in the space. Thus, in the southern part of the region, we have only two peaks in precipitation in the 7 and the 15 decade, and than a precipitation lack during the rest of summer and autumn, whereas in the north there are 3 high peaks and 1 low peak in rainfall. In the middle part of the study area between 48° and 49° latitude, one can distinguish at least 2 high peaks and 1 low peak, at the 7, the 12, and the 21 decade. The hovmoller's diagrams exhibit that the within-season cycle of NDVI corresponds stronger with patterns in temperature than with that of precipitation amounts. An additional correlation analysis has to prove this assumption statistically.

Considerable uniform time-series behaviour during the growing season exists in each year also among the vegetation types (Figure 5). All vegetation types have NDVI values under zero at the beginning of the growing season, in April. Generally, all vegetation types display increases in NDVI from April into June-July, followed by permanent decreases in August-October. Generally, the 16-year average NDVI time-series of the vegetation types show uniform behaviour through the growing season. The dry steppe grassland, semi-desert grassland and desert shrubland have approximately similar values during the spring months April-May. The separation in NDVI values begins in the first decade of June. Despite similar values of NDVI during the spring, the desert shrubland and the semi-desert grassland exhibit lower NDVI values than the dry steppe grassland during the summer and the first month of the autumn, September. In October, the NDVI values of all three vegetation types become again almost analogous.

Desert vegetation begins its development earlier in spring than semi-desert and steppe and culminates in a minimum in late July or at the beginning of August. Usually, the NDVI associated with the desert vegetation turns over the zero in the first decade of April. The semi-desert vegetation begins its growing season in the second decade of April, and after that, this makes the short grassland associated with the steppe areas. During the spring months a rapid increase of NDVI values follows. The shrub vegetation of the desert zone reaches the maximum value between first and third decade of May, depending on the rainfall regime of the associated year. After that, the values decrease permanently during the summer and autumn months, reaching their minimum at the end of October. The grass/shrub regions show their maximum NDVI value, generally, in mid June. As well as the short grassland of the steppe regions, then its NDVI values remain high until mid July, afterwards decreasing slowly until the end of the growing season. The 16-year average seasonal cycle of NDVI provides a clear distinction between the major vegetation types. The best distinction between the time profiles can be made within the summer months, from June to August. During this time, the vegetation types display quite different and clear distinguishable attributes of their canopy such as leaf area, percent coverage, and biomass. These differences in the vegetation cover attributes reflect in clear differences in the 10-day NDVI time-series. The highest discrepancy between NDVI values of the separate vegetation types is observed in the mid June when the vegetation types exhibit their NDVI maximums: dry steppe 0.35, semi-desert 0.25, and desert 0.13.

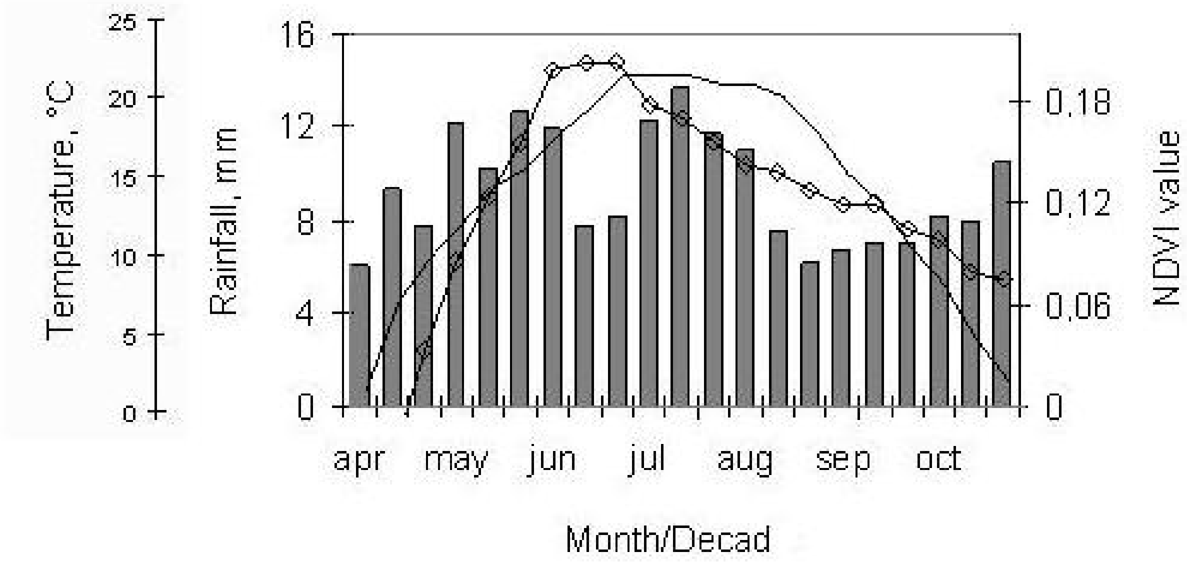

Figure 3. *NDVI (line with squares), precipitation (pillars) and temperature (solid line) for each 10-day period of the growing season (spatially averaged over the entire region and temporally averaged over the period 1985-2001)*

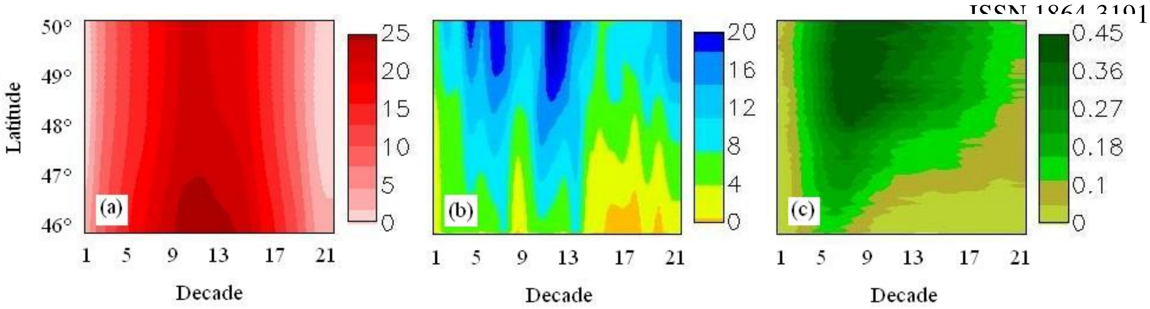

***Figure 4**. Within-season dynamic of climatic parameters and NDVI. (a) Hovmoller's diagram of 10-day mean temperature through April-October showing a uni-modal distribution pattern. The temperature increases progressively from the first decade of April to the third decade of July overall in the study region. After that, the temperature slowly drops during the rest time of the growing season. Panels (b) and (c) demonstrate the corresponding hovmoller's diagrams for precipitation and for NDVI*

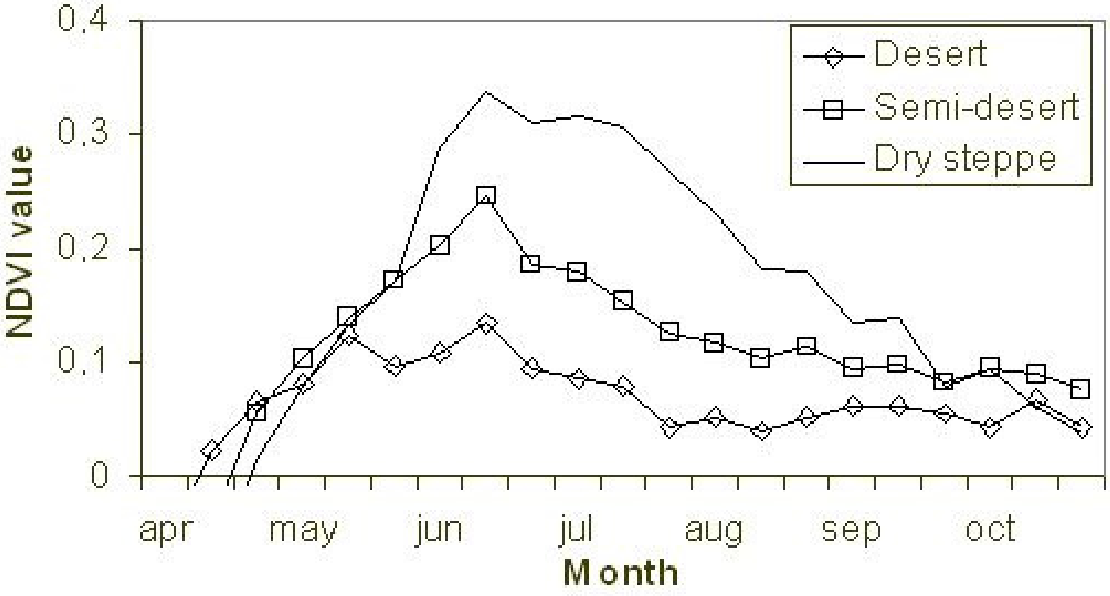

***Figure 5**: Temporal behaviour of spatially averaged NDVI for desert, semi-desert and dry steppe within the growing season. Note the drifting of the peaking time from May, to June, and to the beginning of August observed for desert, semi-desert and steppe vegetation, accordingly*

Reasons for a large discrepancy is a large difference in moisture and temperature conditions over the territory of the study area and differential responses of vegetation cover to climate conditions such as responsiveness to precipitation or limitations from high temperatures. In this section we abandoned a description of existing influence of climatic predictors on vegetation development during the phenological cycle. This influence is very versatile and complicated, it reveals differently during various time-periods of phenological cycle. We carried out a detailed investigation of relationships between NDVI and ecoclimatic parameters during the growing season and devoted two separate sections to the results description. Temporal responses of vegetation cover to climatic factors within the growing season will be examined in detail in the following chapters.

Relationships between NDVI and precipitation

For natural vegetation, precipitation is usually a major source for soil root zone moisture, which is critical to plant survival and productivity. It was reported that change in NDVI of native vegetation during the growing season can be affected by the amount and timing of rainfall (Schultz & Halpert, 1995). The previous studies have also shown presence of a time lag between a weather event, especially rainfall, and the vegetation response to it (Yang *et al.,* 1998; Wang *et al.,* 2003; Richard & Poccard, 1998). Figure 3 and 4 illustrate that there is a time lag of approximately 2-3 decades between precipitation and NDVI time-series averaged over the whole study area. On the contrary, the profiles of NDVI and temperature are synchronous. Therefore, while analysing NDVI-precipitation relationship for individual land-cover classes, we calculated correlation coefficients imposing different time lags from 1 to 9 decades. Significance level of 0.95 was set for all correlation calculations.

At the scale of the entire study area, correlations calculated with time lags of 0-3 decade imposed to the NDVI data have been significant and strong. The highest correlation coefficient was achieved by imposing a time lag of 2 decades. Figure 6 shows the corresponding scatter plot between 10-day NDVI and 10-day rainfall amount. About 38 % of all variations in NDVI are explained by variations in rainfall. This devises a high dependence of vegetation growth on rainfall but a large amount of NDVI variance remains unexplained. It means that other explanatory factors may play an important role too. These predicting factors may be both of climatic and non-climatic nature such as air and soil temperature, evaporation, parent rocks, soil type or vegetation type (Farrar et al., 1994; Yang et al., 1997). Another problem is that a spatial average over the entire study region gives a good general impression of the relationship between vegetation activity and precipitation but it screens response of individual vegetation types and vegetation communities to the climatic factor to be investigated. To investigate this response, we performed correlation analysis disaggregating the territory into areas occupied by different vegetation types.

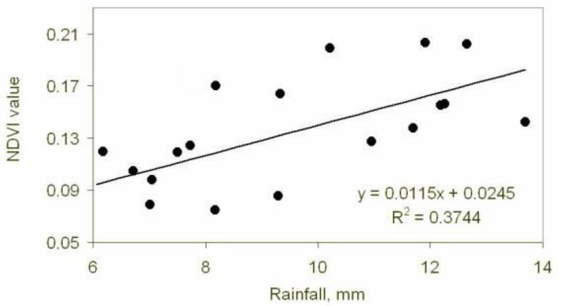

Figure 6*: Relationships between 10-day NDVI and 10-day precipitation. The graph presents results derived with the area-averages of the both variable*

Stratification of NDVI-precipitation relationships by vegetation type

For the land cover types, correlation coefficients between NDVI and precipitation are high in specific combinations of time duration and lag. The rainfall lag periods varied up to six 10-day periods. It indicates the time period for which the influence of rainfall on NDVI is the strongest. The results exhibited that the rainfall time lag increases with an enlargement of partial values in grass species in vegetation cover. The imposed time lag continually increases from desert shrubland, over semi-desert, to short grassland, and to steppe grassland (Figure 7). For desert shrubland, the best correlation between 10-day NDVI and precipitation is achieved by imposing no time lag, for semi-desert by imposing a time lag of 1-2, for short grassland and steppe grassland the best time lag is 3-4 decades.

In terms of the strength of the NDVI-precipitation relationship, it gradually increases from desert shrubland, to semi-desert, to short grassland and to steppe vegetation, with a maximum value of correlation coefficient of 0.49, 0.54, 0.58 and 0.67, respectively. Vegetation cover of irrigated cropland and tundra exhibits only weak response to precipitation. This seems to be explained best by the diversity that exists between the different vegetation species associated with each vegetation type. The results of this analysis are in agreement with the research results obtained by others for dry regions (Yang et al., 1997; Wang et al., 2003; Richard & Poccard, 1998). In accordance with the results, higher correlation coefficients between NDVI and precipitation are observed in landscapes with natural grassland vegetation cover. Correlations are getting weaker with a decrease of grasses in the vegetation cover.

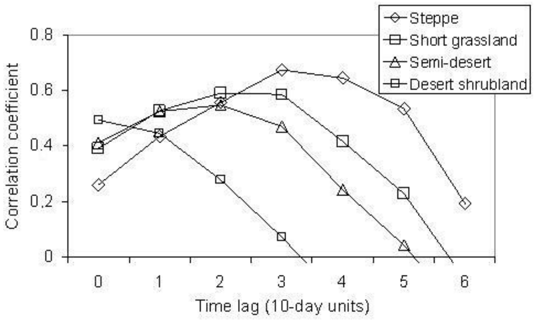

Figure 7. Dependence of correlation coefficients between 10-day NDVI and precipitation on time lag imposed

Relationships between NDVI and temperature

The calculated NDVI-temperature correlation coefficients indicate that there is a significant relationship between NDVI and temperature for all vegetation types. 10-day NDVI was strongly correlated with temperature indices of the same period. We found no time lag in any vegetation type. The value of correlation coefficient between NDVI and temperature was 0.63, 0.70, 0.76 and 0.84, for desert shrubland, semi-desert, short grassland and steppe grassland, respectively.

Temperature often serves as an indirect measure of available energy for plant growth. Above a certain base temperature, a plant’s rate of growth is found to be proportional to temperature. Figure 8 displays that for all vegetation types within-season NDVI-temperature correlation coefficient was higher than that obtained for NDVI-precipitation. This agrees with the results reported by Li et al. (2002) for China and by Yang et al. (1998) for Nebraska, U.S.A.

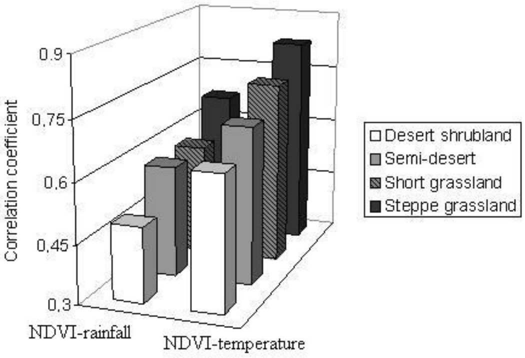

***Figure 8**. Comparison between the values of correlation coefficient obtained for NDVI-precipitation (left row of pillars) and NDVI-temperature (right row of pillars) relationship*

Spatial patterns in NDVI-climate relationship

The results of this study show that 70.52% and 94.90% of all pixels exhibited significant positive correlation (r > 0.48) between 10-day time-series of NDVI-rainfall and NDVI-temperature, respectively. The pixels with high correlation coefficients (r > 0.70) are mainly distributed in the north, south-west and east portion of the study area (Figure 9 and Figure 10, a, b). The total area of pixels varied substantially by land-cover type and increased from desert shrubland, to semi-desert, to short grassland and to steppe.

Significant NDVI-rainfall correlations were observed for 24.72%, 65.56%, 84.65%, and 98.41% of all pixels for every vegetation type, respectively. Compared with temperature, precipitation plays a minor role in explaining the greening patterns in these land-cover types. Only for steppe grassland, precipitation makes a scarcely higher contribution to the greening patterns than temperature does.

The results also exhibited a clear spatial pattern in time lag duration imposed by calculation of correlation coefficient between NDVI and precipitation. Figure 10 (c) shows that the time lag duration generally increases in order from south to north. If we compare the map on Figure 10 (c) with the map of vegetation types (Figure 2), we will consider a strong association between them. The vegetation type in the south, with a shorter time lag of 1, is desert shrub according to the vegetation map, while the land cover type in the north, with a longer time lag of 3-4, is steppe grassland. This agrees with our results derived for spatially averaged data. NDVI is affected by precipitation and this effect occurs with a time lag of 0-4 ten-day periods after the precipitation. The length of the time lag is dependent on land cover type and shows strong spatial patterns in the study area.

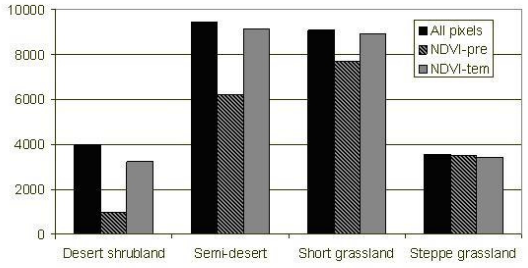

***Figure 9**. Complete amount of pixels, amount of pixels that exhibited significant NDVI-precipitation, and amount of pixels with significant NDVI-temperature correlation for every vegetation type*

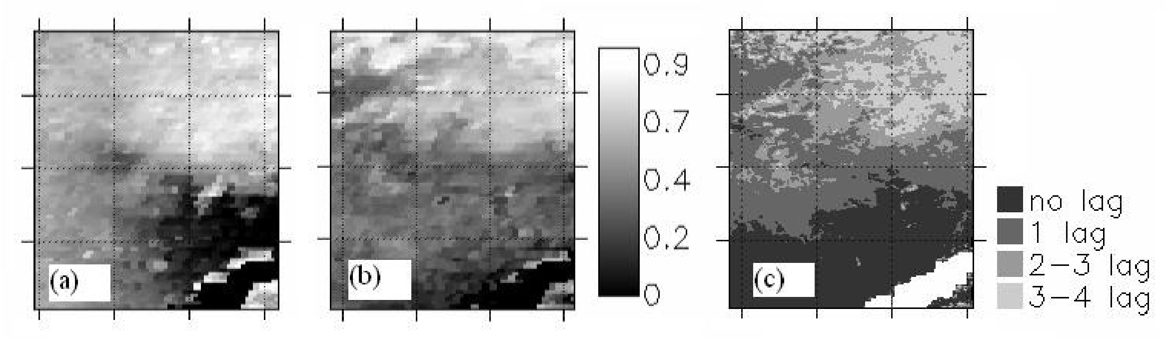

***Figure 10**: Spatial distribution of correlation coefficient for NDVI-temperature (a), and (b) NDVI-precipitation. Panel (c) displays the spatial distribution of time lag (10-day units) given the best correlation between NDVI and precipitation*

Discussion and conclusion

The present work is the first study on the dynamics of drylands vegetation in Kazakhstan that investigated the problem from different views and combined analyses at multiple time- and spatial scales. This study examined within-season interrelations between 10-day time-series of NOAA AVHRR NDVI and analogous series of precipitation and temperature variables over the 1985-2001 growing seasons in drylands of the region Northern Balkhash.

The results illustrated that satellite based vegetation reflectance data can serve as a good proxy for studying the vegetation cover and its variability in drylands ecosystems. Mean growing season and mean seasonal NDVI clearly reflect differentiation of vegetation cover in the study area and make possible its stratification by vegetation types, their values increase in the direction from desert to short grassland and to steppe grassland. The use of NDVI dataset enabled (1) to recognize patterns in vegetation activity over the geographical space of the study area, (2) to extract temporal signals of vegetation variations and (3) to map the spatial patterns of the relationship between vegetation and climate dynamics. The NDVI data revealed substantial sensitivity to the climatic signal both in time and space and allowed the investigation of the influence of climate on the ecosystem.

Strong correspondences between NDVI-precipitation, and NDVI-temperature were observed. The strength of NDVI-climate associations depends on vegetation type but there are variations in the response of NDVI to climate factors within each vegetation type on the per-pixel basis. The analysis exhibited that the correlations were stronger in areas dominated by grass vegetation and weaker in areas dominated by shrubs. This result is consistent with the observation of the relations between NDVI and climate parameters in dry regions throughout the world (Yang et al., 1997; Wang et al., 2001 and 2003; Li et al., 2002). Distinct time lags associated with NDVI's response to precipitation events were determined. Time lags increase in order from desert, to semi-desert and to steppe showing a different reaction speed of vegetation to precipitation events.

The correlation between NDVI and temperature was found to be higher than correlation between NDVI and rainfall. These results degree with the results reported by Li et al. (2002) and Xiao & Moody (2004) for China's drylands but disagree with the results reported by Wang et al. (2001 and 2003) for Great Plain's drylands. Our analyses also showed that temperature has a higher impact on plant growth throughout the growing season. In comparison to precipitation, the correlation between NDVI and temperature was for all vegetation types higher. This was observed both for spatially averaged data and at per-pixel scale. The influence of temperature on the vegetation growth was positive during the early and late growing season, while during the mid of growing season, when the temperature achieves its maximal values, it causes the reducing or even the stop of the plant growth. On the one hand, the temperature is the most important predicting factor at the beginning and the end of the growing season because plants can grow only under definite temperature conditions, namely, when temperature rises over zero. On the other hand, when the temperature continues to grow and reaches its maximum values in June-July, it stresses the vegetation and restrains the plant growth. Probably, during these months, precipitation begins to play the main role in determining vegetation development. At the end of the growing season the temperature rapidly drops across the entire region. In the areas where it does not drop below the 5° C limit the vegetation can rehabilitate for a short time again. This was observed in the desert zone.

The study results improve the understanding of the nature and mechanisms of the ecosystem dynamics in the internal Eurasia and provide the basis for predicting changes in productivity that accompany changes in climate and human activity.

Acknowledgments

The study was a part of a PhD thesis written by Pavel Propastin and supervised by Prof. Dr. M. Kappas and Prof. Dr. G. Gerold, Institute for Cartography, GIS, and Remote Sensing in the Department of Geography (Georg-August-University, Göttingen). The work was a part of a larger project aimed to improvement of drylands management in Kazakhstan. The project was funded by the National Academy of Science of Kazakhstan and the World Development Bank. Some of the results of this study were presented at the 2nd Göttingen GIS & Remote Sensing Days on 4-6 October 2006.

References

Budde, M. E., Tappan, G., Rowland, J. Lewis, J. and Tieszen, L. L. 2004. Assessing land cover performance in Senegal, West Africa using 1-km integrated NDVI and local variance analysis. J. of Arid Environments, 59: 481-498.

Evans J. and R. Geerken. 2005. Discrimination Between Climate and Humane-Induced Dryland Degradation. J. of Arid Environment, 57: 535-554.

Foody G. M. 2003. Geographical weighting as a further refinement to regression modelling: an example focused on the NDVI-rainfall relationship. Remote Sensing of Environment 88, 283-293.

Gisladottir, G. & Stocking, M. 2005. Land degradation control and its global environmental benefits. Land Degrad. & Develop. 16, 99-112.

Ji, L. and A. J. Peters. 2004. A Spatial Regression Procedure for Evaluating the Relationship between AVHRR-NDVI and Climate in the Nothern Great Plains. International Journal of Remote Sensing, 25: 297-311.

Kogan, F. N. 1997. Global drought watch from space. Bulletin of the American Meteorological Society 78, 621-636.

Kowabata A., Ichi K. & Yamaguchi Y. 2001. Global Monitoring of Inter-annual Changes in Vegetation Activities Using NDVI and its Relationship to Temperature and Precipitation. Int. J. Remote Sensing 22, 1377-1382.

Li B., Tao S. & Dawson R. W. 2002. Relation between AVHRR NDVI and ecoclimatic parameters in China. Int. J. Remote Sensing 23, 989-999.

Li J., Lewis J., Rowland J., Tappan G., Tieszen L., 2004. Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series. J. of Arid Environments 59, 463-480.

Los S. O. 1993. Calibration Adjustment of the NOAA AVHRR Normalized Difference Vegetational Index Without Resource to Component Channel 1 and 2 Data. Int. J. Remote Sensing 14, 1907-1917.

Nicholson, S. E. & Farrar, T. J. 1994. The influence of soil type on the relationships between NDVI, rainfall and soil moisture in Semiarid Botswana. I. NDVI response to rainfall. Remote Sensing of Environment 50, 107-120.

Richard Y. & Poccard I. 1998. A statistical study of NDVI sensitivity to seasonal and interannual rainfall variations in southern Africa. Int. J. Remote Sensing 19, 2907-2920.

Schultz P. A. & Halpert M. S. 1995. Global Analysis of the Relationships Among a Vegetation index, Precipitation and Land Surface Temperature. Int. J. Remote Sensing 16, 2755-2776.

Tateishi, R. & Ebata, M. 2004. Analysis of phenological change patterns using 1982-2000 Advanced Very High Resolution Radiometer (AVHRR) data. Int. J. Remote Sensing 25, 2287-2300.

Tucker C. J. and P. J. Sellers. 1986. Satellite remote sensing of primary vegetation. Int. J. Remote Sensing 7, 1395-1416.

Tucker C. J., Slayback D. A., Pinzon J. E., Los S. O., Muneni R. B. & Taylor M. G. 2001. Higher northern latitude Normalized Difference Vegetation Index and growing season trends from 1982 to 1999. Int. J. Biometeorol. 45, 184-190.

Tucker, C. J., Vanpra, C. L., Sharman, M. J.,Van Ittersum, G. 1985. Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel: 1980–1984. Remote Sensing of Environment 17, 233–249.

Wang J., Price K. P. & Rich P. M. 2001. Spatial patterns of NDVI in response to precipitation and temperature in the central Great Plains. Int. J. of Remote Sensing 22, 3827-3844.

Wang J., Rich P. M. & Price K. P. 2003. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. Int. J. of Remote Sensing 24, 2345-2364.

Xiao, J. and Moody, A. 2004. Trends in vegetation activity and their climatic correlates: China 1982 to 1998. International Journal of Remote Sensing, 25: 5669-5689.

Yang L., Wylie B., Tieszen L.L., Reed B. C., 1998. An analysis of relationships among climate forcing and time-integrated NDVI of grasslands over the U.S. Northern and Central Great Plains. Remote Sensing of the Environment 65, 25–37.