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Impact of Interannual Variability of Meteorological Parameters on Vegetation Activity over Mongolia

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Abstract

This study is designed to elucidate the impact of interannual variability of meteorological parameters on vegetation activity over Mongolia using 10-day composite NDVI (Normalized Difference Vegetation Index) data set and surface meteorological data (precipitation, temperature and snow depth) for 97 meteorological stations from 1993 to 2000.

The analysis is made on vegetation in two developmental stages; the rapid-growth stage (almost June to July) and the mature stage (almost July to August). Positive correlations at 99% significant level between precipitation and vegetation activity are recognized for 29% and 42% of meteorological stations in the rapid-growth stage and the mature stage, respectively. Precipitation in June and July affects vegetation activity in both stages.

The impact of air temperature on vegetation activity in the mature stage differs by season. The vegetation activity is negatively correlated with summer temperature over most area. Negative correlations are found over the western part of Mongolia with respect to temperature in early winter, and positive correlations are concentrated in the northeastern part of Mongolia with respect to temperature in midwinter. Furthermore, there are five meteorological stations near the Khenty Mountains, with high correlation coefficients between snow depth and vegetation activity in the rapid-growth stage; however, the snow depth effect is limited to a narrow region.

The possibility of prediction the vegetation activity in the two stages is examined using a multiple regression method, based on the above-mentioned results. Since correlation coefficients between observed vegetation activity and estimated vegetation activity from the multiple regression equations are high satisfactorily, it is found that the prediction algorithm has a potential for the prediction of NDVI over Mongolia.

1. Introduction

Mongolia is located in the transition zone for vegetation, where it ranges from tiga forest in the north to desert in the south. Rangeland in Mongolia covers 1.26×10^6 km^2 and occupies 97% of the country. It is classified into five subtypes; high mountains (4.5%), forest steppe (23%), steppe (28%), desert steppe (28%) and desert (16%) (Bolortsetseg et al. 2000). These rangelands are the main source of forage for nomadic livestock, so that productivity of a grass in the rangeland gives their life direct influence. For example, Morinaga et al. (2004) showed that poor biomass production, due to the preceding summer drought is a crucial cause for a large amount of livestock loss in winter (the so-called *dzud*).

Since a warming trend in winter months has been recognized in the past 40–60 years (Yatagai and Yasunari 1994; Natsagdorj 2000), the annual precipitation has exhibited a slight increasing trend in most areas except for the de-

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serts, but spring dryness has occurred during the last 60 years (Natsagdorj 2000). Climate change is expected to have a large impact on nomads and agriculture. Knowledge on a possible affect of climate change on productivity of the rangelands, is important for Mongolian society. Furthermore, Xue (1996) showed that decrease in vegetation activity over the Mongolian grasslands plays an important role in modifying the East Asian monsoon circulation, and in producing a rainfall anomaly over China. It is suggested that interannual variability of vegetation activity in the grasslands, has a significant affect on not only Mongolian society, but the East Asian climate as well.

In order to make clear the impact of climate change on vegetation activity globally, many researchers have studied the relationship between NDVI (Normalized Difference Vegetation Index) and meteorological parameters. These studies are classified into two types. The first type is the study on the relationship between the seasonal pattern of the meteorological parameters and the seasonality of NDVI. Schultz and Halpert (1993) showed that vegetation is limited by temperature in cold regions, and by both temperature and rainfall in temperate regions. The monthly timing of the maximum of NDVI was associated with the seasonal pattern of temperature and rainfall (Moulin et al. 1997), and a delay of 1 to 2 months was frequently observed in the maximum of NDVI with respect to rainfall in drier climates (e.g., Schultz and Halpert 1995; Santos and Negri 1997; Potter and Brooks 1998). According to a global analysis of Schultz and Halpert (1995), positive correlations between NDVI and both rainfall and surface temperature, was recognized over Mongolia.

The second type is the study on the affect of the anomaly of the meteorological parameters on NDVI anomalies, and this study is based on this viewpoint. The large positive correlation between NDVI anomaly and surface temperature anomaly tend to occur in Siberia and other extreme northern regions (Schultz and Halpert 1995). On the other hand, a negative correlation was recognized mainly in mid-latitudes, including some parts of Mongolia (Nemani et al. 1993; Schultz and Halpert 1993, 1995). Anomalies of rainfall and NDVI are positively correlated over drier regions in the world (e.g., Samuel and Prince 1995; Schultz and Halpert 1995; Salinas-Zavala et al. 2002). Shinoda and Gamo (2000) showed that the rainfall anomaly preceded the NDVI anomaly by about 1 month around the African Sahel. Positive lag correlation was also recognized between the NDVI anomaly and the rainfall anomaly in the antecedent month in the eastern part of Mongolia (Schultz and Halpert 1995).

Since most of these global investigations were based on coarse global meteorological data sets, which are not suitable to elucidate the features of regional scales, it is necessary to re-examine using data from meteorological stations over Mongolia. Furthermore increasing the number of observations improves the quality of analysis. For example, Miyazaki et al. (2004) pointed out that significant positive correlation were found for rainfall in July and LAI (leaf area index) in August, and significant negative correlation for air temperature in June and LAI in June at Arvaikheer of central Mongolia. However, there are few studies on the relationship between vegetation activity and meteorological elements over all of Mongolia. The purpose of this study is to describe the affect of interannual and seasonal variability of precipitation, air temperature and snow depth on NDVI over Mongolia using data from a large number of meteorological stations. Furthermore, the prediction possibility of vegetation activity will be examined based on results of the analysis.

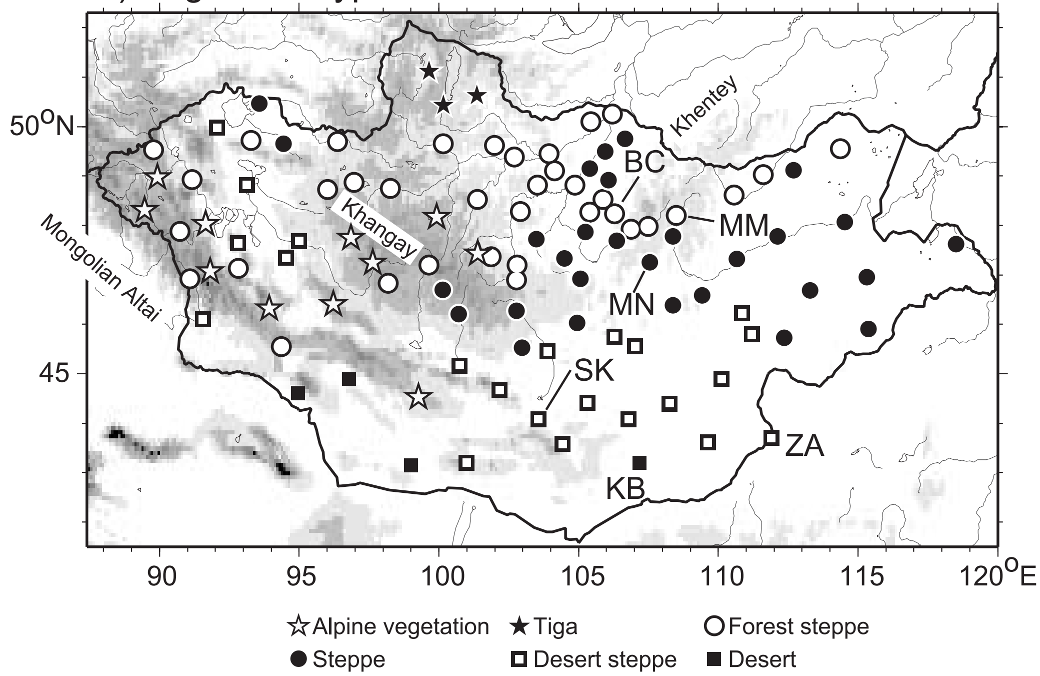
2. Data

Data used in this analysis are surface meteorological data set, provided by the Institute of Meteorology and Hydology, Mongolia and Twenty-year Global 4-minute AVHRR (Advanced Very High Resolution Radiometer) NDVI Dataset of Chiba University (10-day composite NDVI data set).

2.1 Surface meteorological data set

The surface meteorological data set contains 3-hourly air temperature, twice-daily precipitation (0 and 12 UTC = 8 and 20 LT) and daily snow depth measurements from January 1993 to December 2000 for 97 stations (Fig. 1). Meteorological parameters are averaged in 30-day intervals for every 10-day period. However, there are more than a few "no observation"

a) Vegetation type



b) Annual precipitation

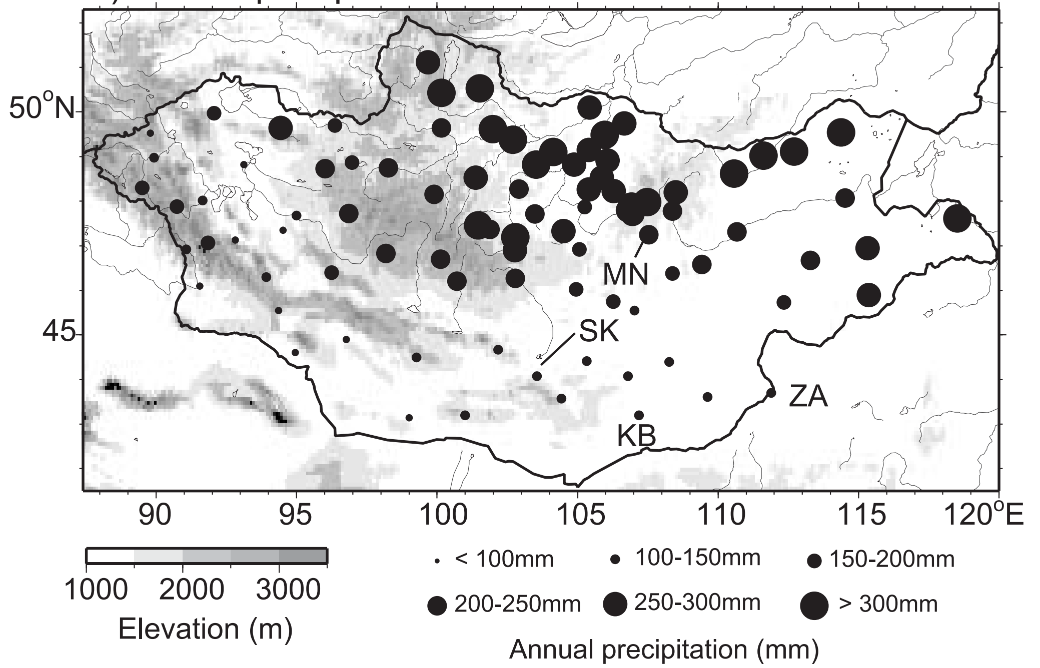


Fig. 1. Distribution of meteorological stations with vegetation type (a), and mean annual precipitation (b). Symbols indicate the name of meteorological stations mentioned in the analysis; BC: Bayanchandanima, MM: Mongenmorit, MN: Monnit, SK: Saikhanvoo, KB: Khanbogd and ZU: Zamum-uud.

values and error data in the data set. These data are treated as missing values. If the missing values were more than 10% in the 30-day interval, these averaged meteorological data were not used for the analysis.

2.2 10-day composite NDVI data set

Eight years NDVI data from 1993 to 2000 are used in the present analysis. NDVI data are generally found to be well correlated to the fraction of photosynthetically active radiation absorbed by green vegetation, and a good indicator of biomass production (e.g., Tucker 1979). The NDVI value of the pixel in which a meteorological station is located is regarded as a proxy of the biomass production.

The source of 10-day composite NDVI data set is the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) Pathfinder global 10-day composite 8 km AVHRR NDVI data (Tateishi 2001). The NDVI is defined as the ratio;

$$\mathrm{NDVI} = (\mathrm{Ch2} - \mathrm{Ch1})/(\mathrm{Ch2} + \mathrm{Ch1}).$$

Where Ch1 is the reflectance in the visible wavelengths (580–680 nm), and Ch2 is the reflectance in the reflective infrared wavelengths (725–1100 nm). The atmospheric correction applied to both reflectance data are for Rayleigh scattering and ozone absorption. Only data within 42 deg of nadir were used in order to remove scan angle biases due to bi-directional effect, and highest NDVI value is the composite method used in Pathfinder processing of 10-day composite (James and Kalluri 1994).

High-frequency noises due to cloud and signal noise in the Pathfinder global 10-day composite NDVI data were removed using a temporal window operation method, so as to make a smooth temporal NDVI change (Park et al. 1999), and map projection was changed from Interrupted Goode Homolosine projection to Plate Carree projection for easier usage of the data.

3. Method

3.1 Definition of two development stages and vegetation activity

In this analysis, affect of interannual variability of meteorological parameters on NDVI will be investigated for each meteorological station in two developmental stages which are fixed to a calendar; the rapid growth stage and the mature stage. In other words, they are climatological developmental stages of plants. However, the time when NDVI reaches a maximum differs greatly by location, which means that the phase of development stage of plants also differs greatly by location (see, Fig. 3b). The climatological developmental stage of plants should be defined at every meteorological station.

Figure 2 shows the seasonal variation of 8-year mean NDVI and NDVI in 1997 at Mannit in steppe vegetation (MN in Fig. 1). 8-year mean NDVI reached a maximum at the end of August (the 24th 10-day period), and the maximum value will be referred to as $\mathrm{NDVI}_{\mathrm{max}}$, which is equivalent to the climatological maximum value of biomass production in the growing season. As shown in Fig. 2, the mature stage is defined as the 10-day period when 8-year mean NDVI reached maximum, as well as the 20-day period prior to the maximum, and the 20-day period after the maximum. The 22nd to 26th 10-day period is the mature stage

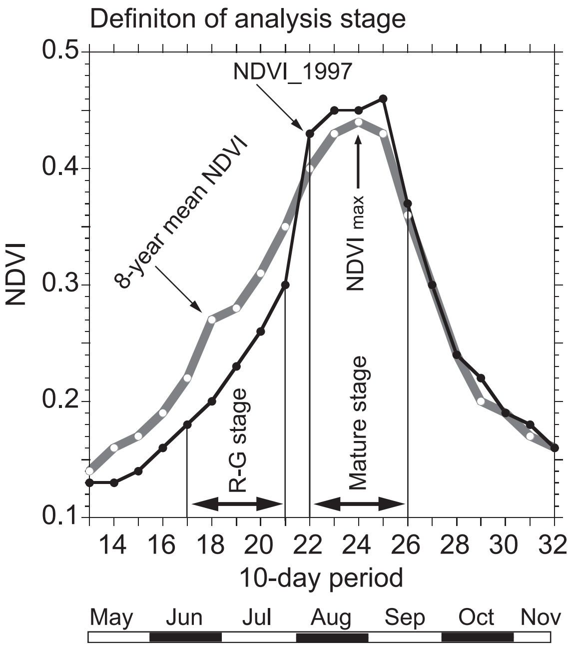


Fig. 2. Definition of the rapid-growth stage (R-G stage) and the mature stage of vegetation activity at Mannit (MN in Fig. 1).

for this station. The rapid-growth stage is defined as before the 50-day period before the mature stage; from the 17th to the 21st 10-day period for this station.

Vegetation activities for each year in the rapid-growth stage and the mature stage are defined as the sum of NDVI value in each stage, respectively, and are used as proxies for the amount of the forage for nomadic livestock. Since NDVI in a sparse vegetation region have some errors due to the influence of the reflectance of background soil (e.g., Huete 1988), NDVI less than 0.1 is considered to be zero. Vegetation activity in the rapid-growth stage over the sparse vegetation in southern Mongolia is contaminated to some degre.

There are no data in this data set from the end of September to December in 1994. As for this period, 7-year mean NDVI value are substituted for the missing data. This process does not influence the results.

3.2 Classification of vegetation type

Vegetation in Mongolia is classified into six categories; alpine vegetation, taiga, forest steppe, steppe, desert steppe and desert. Bolorsetseg et al. (2000) described vegetation type for 41 meteorological stations, and we adopted these classification. Vegetation type for other stations was defined using a map of vegetation distribution by Hilbig (1995). Stations in typical grasslands of forest steppe, steppe and desert steppe, which are a suitable source of forage for livestock, composed about 83% of the total number of stations (see Fig. 1a and Table 1).

Table 1. Number and percentage of stations with lag-correlation coefficient at the 99% significant level between vegetation activities and precipitation for the rapid growth stage (R-G stage) and the mature stage (M-stage).

Vegetation type	R-G stage	M-stage	No. of stations
Alpine vege.	3 (33%)	4 (44%)	9
Tiga	1 (33%)	1 (33%)	3
Forest steppe	7 (19%)	9 (25%)	36
Steppe	11 (42%)	11 (42%)	26
Desert steppe	5 (26%)	13 (68%)	19
Desert	1 (25%)	3 (75%)	4
Total	28 (29%)	41 (42%)	97

3.3 Calculation of correlation coefficient

Meteorological parameters are averaged in 30-day intervals for every 10-day period. 36 mean values are obtained at most for one parameter and one year, and lag-correlation coefficients between meteorological parameters and vegetation activity in the two stages are calculated for all combinations. The maximum value among these lag-correlation coefficients will be discussed in this paper. Since the duration of meteorological parameters and vegetation activity are fixed to a calendar, the correlation coefficients are equivalent to correlation coefficients between anomaly of meteorological parameters and anomaly of vegetation activities.

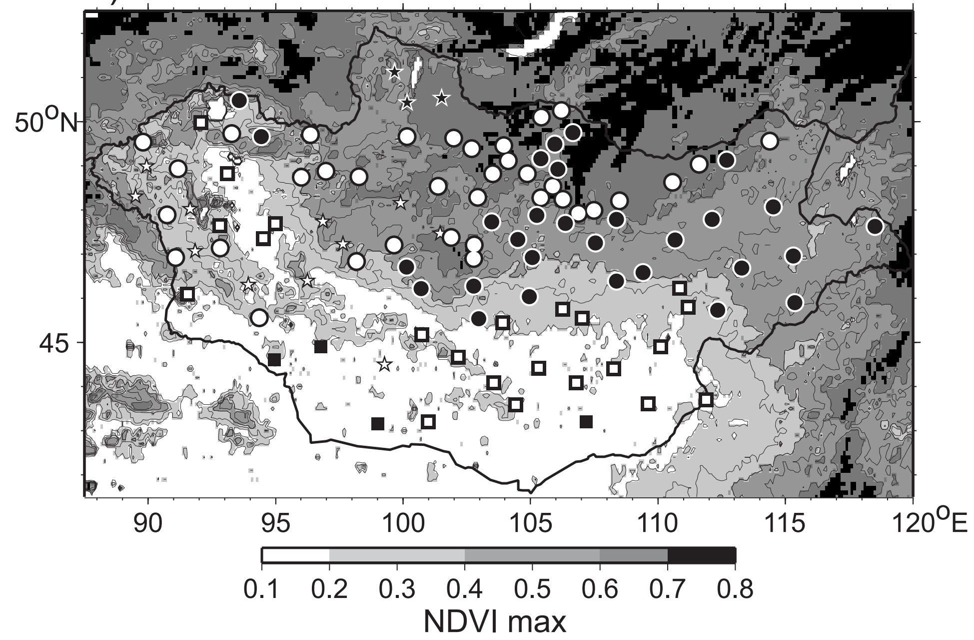
The analysis period is short (8 years). Since the number of data used calculating correlation coefficients is 8 at most, correlation coefficients with less than 99% significant level were neglected in this analysis.

4. Impact of precipitation

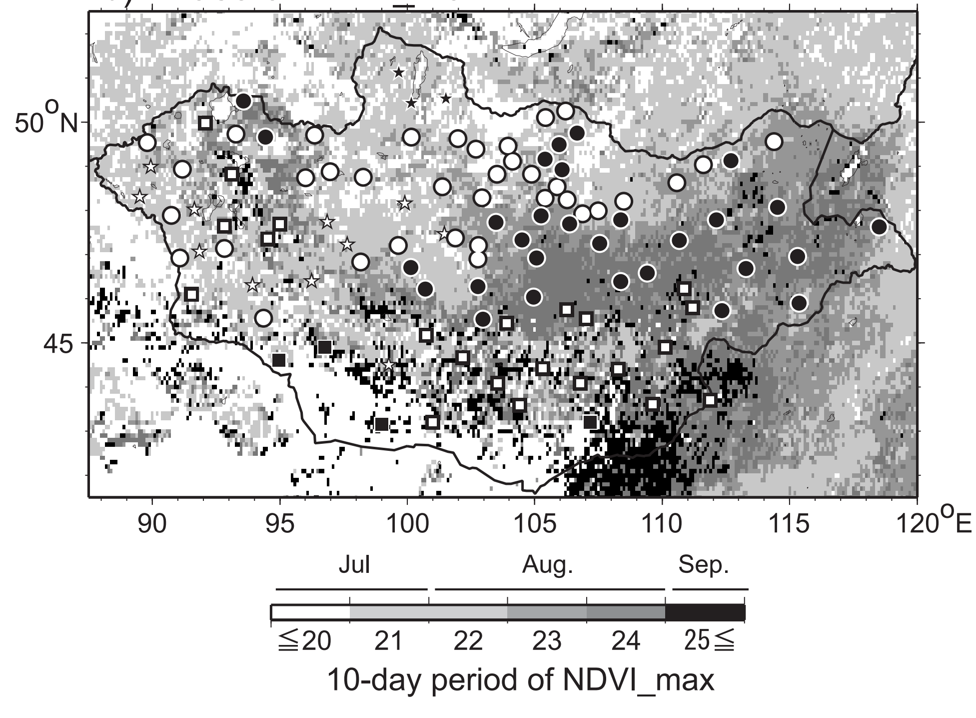
4.1 Mean annual precipitation and mean NDVI features

Mean annual precipitation decreases from north to south (Fig. 1b), which is a decisive factor in the distribution of vegetation zone. Annual precipitation exceeds 350 mm in the tiga vegetation zone and is less than 100 mm in the desert vegetation zone. Figure 3 shows the distribution of the maximum value of $\mathrm{NDVI}_{\mathrm{max}}$, and phase of the seasonal variation of mean NDVI. As shown in Fig. 3a, the maximum value is 0.6–0.7 in northern Mongolia, which corresponds with forest regions, and it decreases gradually from north to south. Maximum values lower than 0.2 in southern Mongolia and the region between Mongolian Altai and the Khangay Mountains, are corresponding to desert steppe and desert. The distribution pattern of $\mathrm{NDVI}_{\mathrm{max}}$ is similar to that of annual precipitation (Fig. 1b), and $\mathrm{NDVI}_{\mathrm{max}}$ is well correlated with mean annual precipitation (Fig. 4). The similar features between NDVI value and annual precipitation are also recognized over the Sahara Desert (e.g., Nicholson and Davenport 1990; Malo and Nicholson 1990; Tucker and Nicholson 1999).

As shown in Fig. 3b, the time when 8-year mean NDVI reaches a maximum varies from the middle of July to the beginning of September. It is noted that the 8-year mean NDVI



a) NDVI max



b) Phase of NDVI_max

Fig. 3. Distribution of the maximum value of 8-year mean NDVI (a) and the time when the 8-year mean NDVI reaches maximum value (b). Location of meteorological station is indicated by the same legend used in Fig. 1a.

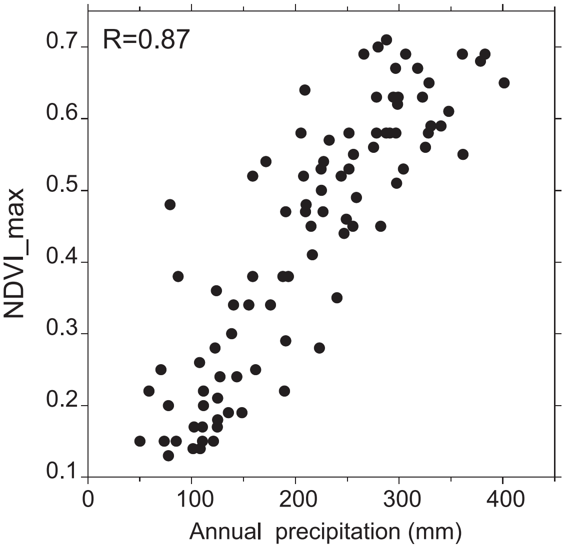


Fig. 4. Relationship between annual precipitation and maximum value of 8-year mean NDVI in Mongolia.

around steppe vegetation tend to reach a maximum from the middle to the end of August, which is 10 to 30 days later than in forest steppe and desert steppe regions. However, the phase of $NDVI_{max}$ seems not to be correlated with annual precipitation.

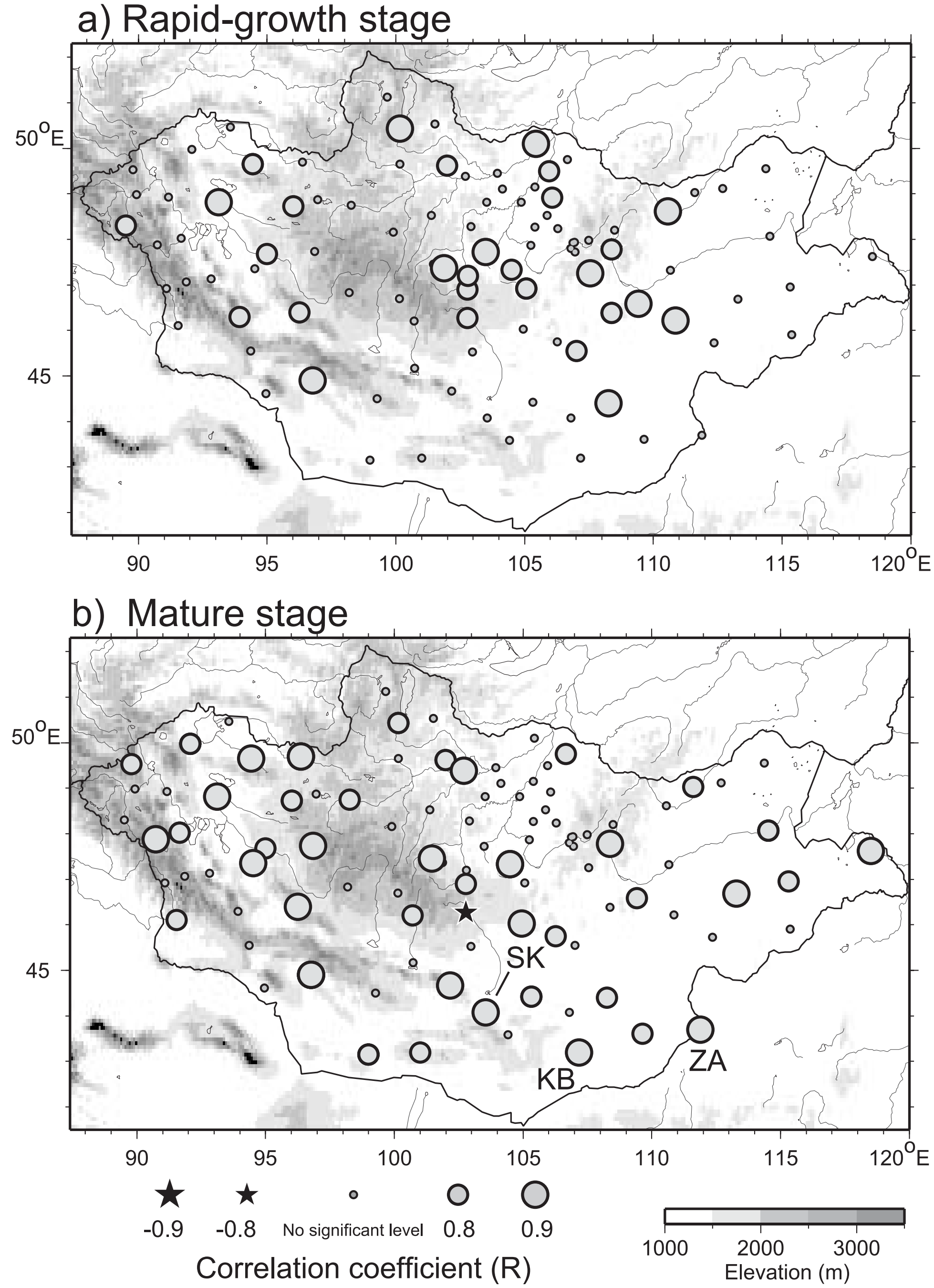
4.2 Interannual variation of precipitation

Figure 5 shows distribution of the maximum lag-correlation coefficient between precipitation and vegetation activity in the two stages. Positive correlations at the 99% significant level ($R >$ about 0.8) are recognized at 29% of all stations in the rapid growth stage (Fig. 5a), and increases to 42% in the mature stage (Fig. 5b). In both stages, there are a few stations with significant correlations around Mongolian Altai, the Khangay Mountains and the Khenety Mountains, where annual precipitation is relatively high for Mongolia.

As shown in Table 1, although there are number of stations with significant positive lag-correlation in the rapid growth stage in steppe (42%) with low annual precipitation, there are not many stations in forest steppe (19%) with high annual precipitation. It is seemed that dry environment make correlation coefficient high. However, the ratio in desert steppe and desert are low against the expectation. There is a possibility that the estimation error of NDVI due to sparse vegetation decreases the correlation coefficient over the desert steppe and desert in the rapid growth stage.

In the mature stage, significant correlation were recognized at 25% of all stations in forest steppe, at 42% in steppe and at 68% in desert steppe, respectively. The correlation coefficient between vegetation activity and precipitation tends to be high in vegetation zones with little annual precipitation, which is consistent with the results of the previous studies (e.g., Samuel and Prince 1995; Schultz and Halpert 1995; Salinas-Zavala et al. 2002). Especially, some stations in arid region exhibit extremely high correlation coefficient. Figure 6 shows the relationship between vegetation activities in the mature stage and precipitation in July in Khanbogd (KB in Fig. 1), and Zamun-uud (ZN in Fig. 1). $NDVI_{max}$ in both stations are the end of August. Their correlation coefficients exceed 0.9 at both locations, however, precipitation in June and August less correlated with vegetation activity ($R = 0.1$–0.4). Since precipitation in July over Mongolia depends on both the first maximum of rainy season and the break of rainy season (Iwasaki and Nii 2006), annual variation of a continental scale circulation affects directly the anomalies of vegetation activity.

Timing of the maximum lag-correlation between NDVI and precipitation differs by station. Figure 7 shows the timing of the maximum lag-correlation coefficient at the 99% significant level relative to the time when mean NDVI reaches a maximum; “0” in the x-axis means the period of the maximum of mean NDVI. When a station had two maxima, these two maxima were counted in Fig. 7. Precipitation in the early rapid-growth stage had impacted on the vegetation activity in the rapid growth stage, and there is not a large time lag. On the other hand, precipitation in the mature stage had almost no influence on the vegetation activity in the mature stage. Precipitation 1–2 months before the mature stage did impact the vegetation activity in the mature stage, which is consistent with the results of the previous studies (Schultz and Halpert 1995; Miyazaki et al. 2004). In other words, precipitation in the rapid growth stage is importance for vegetation activity in both stages.


a) Rapid-growth stage

b) Mature stage

Fig. 5. Distribution of the maximum lag-correlation coefficient at the 99% siginificant level between precipitation amount and NDVI in the rapid-growth stage and the mature stage. Symbols of SK, KB and ZA indicate locations of Saikhanvoo, Khanbogd and Zamum-uud, respectively.

Precipitation 4–5 months before the mean NDVI maximum (April to May) were correlated with vegetation activities in some meteorological stations in Fig. 7. These stations are located between Mongolian Altai and the Khangay Mountains.

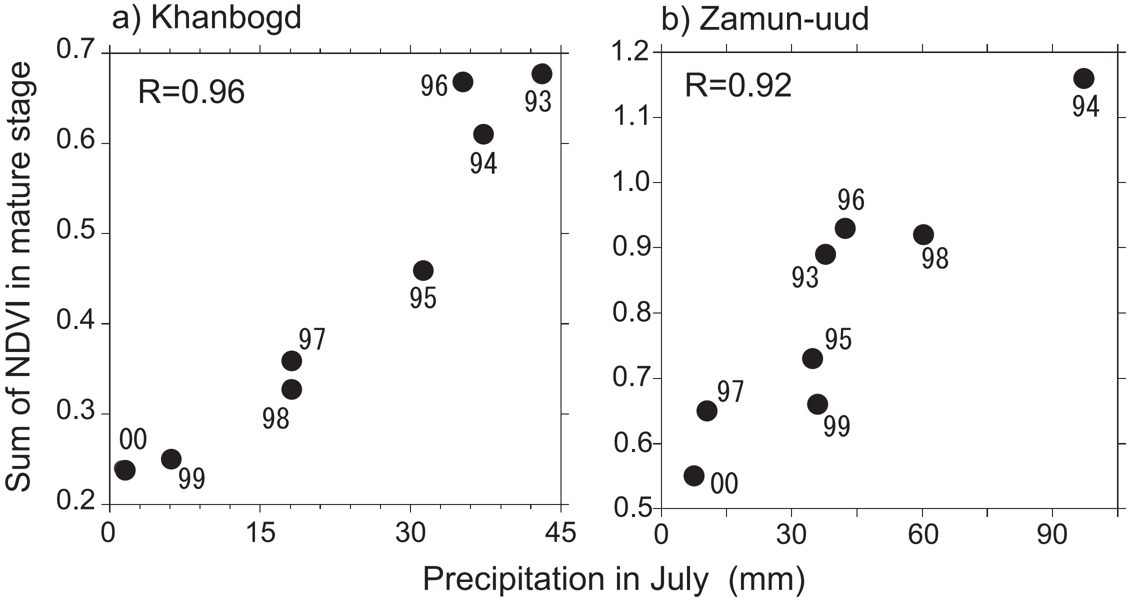


Fig. 6. Relationship between precipitation in July and vegetation activity in the mature stage at Khanbogd (a) and Zamum-uud (b). Two digits in figure indicate the year.

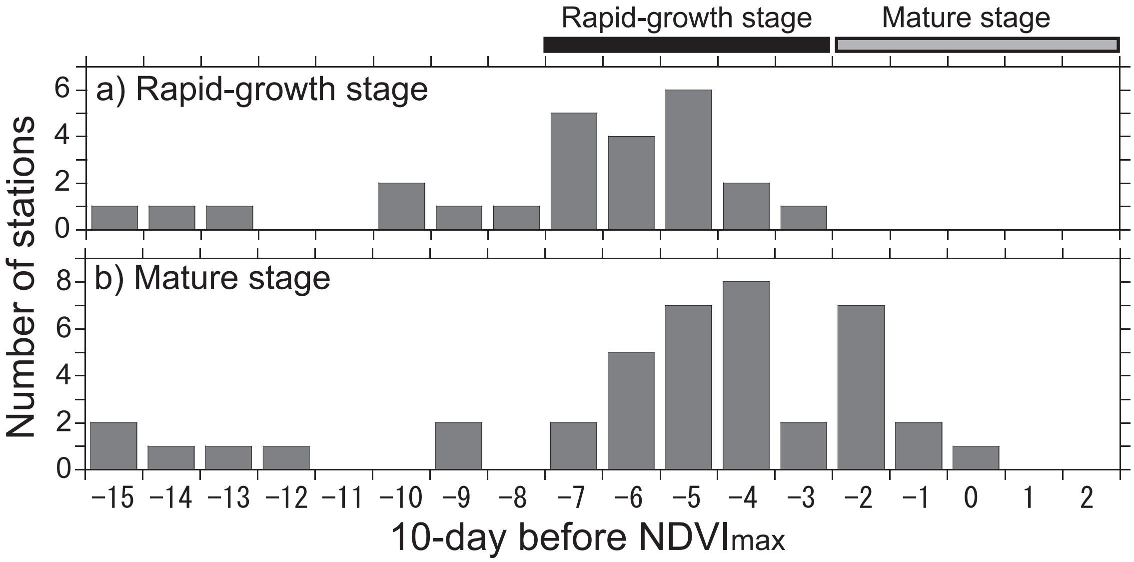


Fig. 7. Timing of the maximum lag-correlation coefficient at the 99% significant level relative to mean NDVI maximum in the rapid-growth stage (a) and the mature stage (b). One station with significant negative correlation in the mature stage in Figure 5b is not counted.

5. Impact of air temperature

Some previous studies used ground temperature estimated from satellite IR data. The data set used in the present analysis also contains ground temperature. The relationship between ground temperature and NDVI is similar to the relationship between air temperature and NDVI, but the lag-correlation coefficients are apparently lower than that of air temperature. Therefore, we will focus on air temperature.

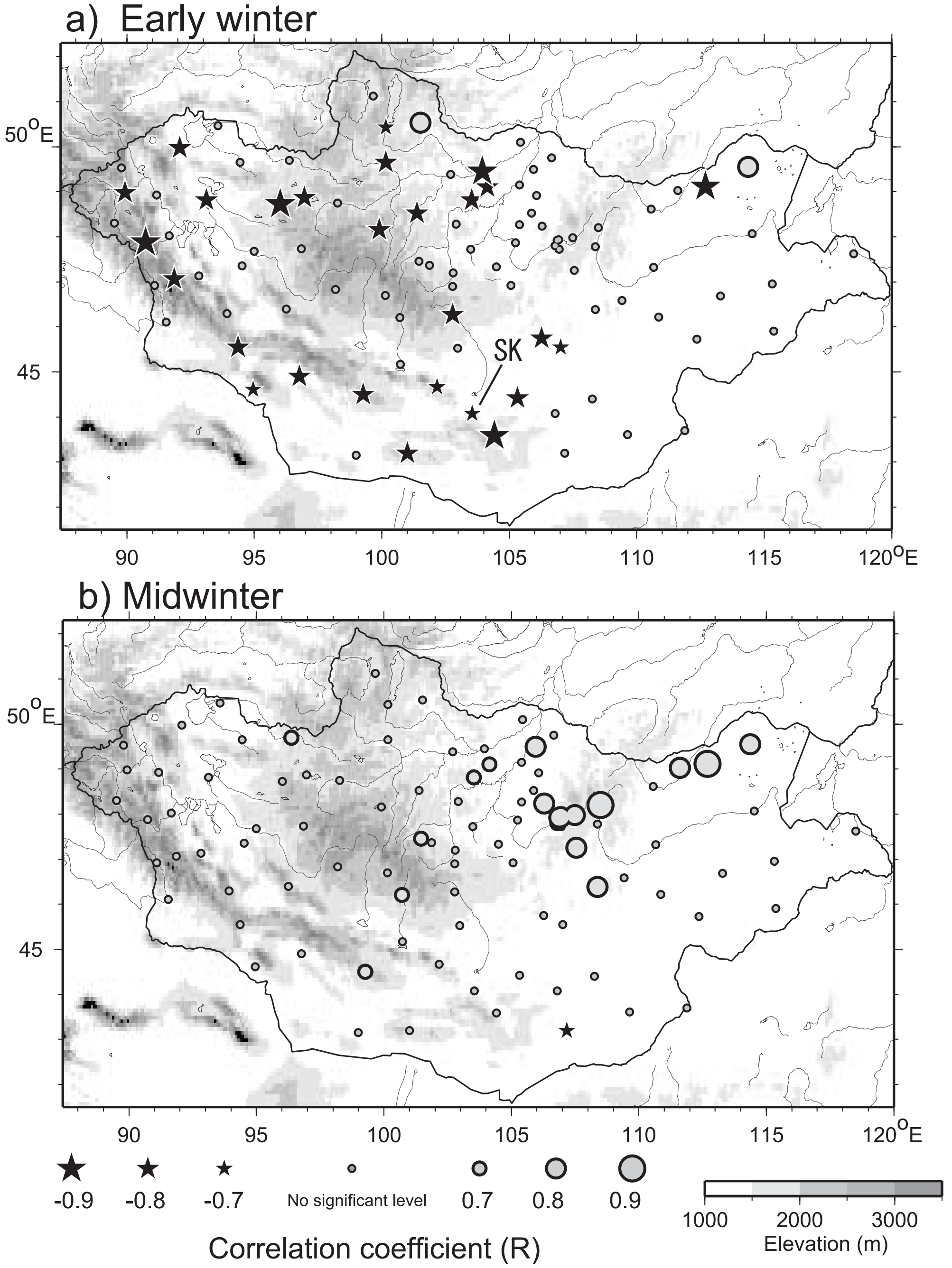


Fig. 8. Distribution of maximum lag-correlation coefficient at the 95% significant level between vegetation activity in the mature stage and air temperature from November to December (a: early winter), and from January to March (b: midwinter). Symbol of SK indicates location of Saikhanvoo.

5.1 Impact of air temperature on vegetation activity in the rapid-growth stage

There are several stations with significant correlation between vegetation activity in the rapid-growth stage and air temperature, however, apparent regularity and systematic distribution could not be found. This feature is worth describing, since high temperature in the rapid-growth stage (spring to early summer) is a generally favorable environment for vegetation. In other words, it is implying that precipitation is a limit factor of vegetation activity, even in the rapid growth stage.

5.2 Impact of winter temperature on vegetation activity in the mature stage

Figure 8 shows the maximum lag-correlation coefficient at the 95% significant level from preceding October to December (early winter), and preceding January to March (midwinter). Correlations with winter temperature are not as clear, so that the 95% significant level was adopted for this analysis only. Correlation features are completely different in the early winter and midwinter. Negative correlations are recognized with respect to the early winter temperature in western and southern Mongolia, and there are fewer correlations in steppe (Table 2). As for impact of midwinter air temperature, correlation coefficients greater than 0.8 are concentrated in forest steppe and steppe in the northeastern part of Mongolia, and no significant correlations are found over the drier regions (Table 2).

Since we could not find any significant correlations between winter temperature and meteorological parameters in summer, the winter temperature might have a direct influence to vegetation activity in the mature stage. The mechanism could not be elucidated, however, these features are very useful to prediction of vegetation activity discussed in Section 7.

Table 2. Number and percentage of stations with lag-correlation coefficients at 95% significant level between vegetation activity in the mature stage and air temperature in the early winter and midwinter. Two positive correlations in Fig. 8a and one negative correlation in Fig. 8b are not counted.

Vegetation type	Early Winter	Mid Winter
Alpine vege.	4 (44%)	2 (22%)
Tiga	1 (33%)	0 (0%)
Forest steppe	9 (25%)	9 (25%)
Steppe	2 (8%)	5 (19%)
Desert steppe	9 (47%)	0 (0%)
Desert	2 (50%)	0 (0%)
Total	27 (28%)	16 (16%)

5.3 Impact of summer temperature on vegetation activity in the mature stage

Figure 9 shows the maximum lag-correlation coefficient between NDVI and temperature at the 99% significant level from May to September. Significant negative correlations are recognized at 26% of all stations in the mature stage (Table 3). As shown in Fig. 10, higher temperature in the mature stage impacted vegetation activity in the mature stage, and these features are consistent with the results of Miyazaki et al. (2004).

Table 3 shows the number and ratio of stations with significant correlation. As for grasslands of forest steppe, steppe and desert steppe, there is correlation at 17–42% of the stations at the 99% significant level, and 44–53% of the stations at the 95% significant level. There is no clear difference among grasslands on the impact of summer temperature. Although the percentage of C4 plant species, which benefit from high leaf temperature and aridity, was larger in desert steppe than forest steppe in Mongolia (Pyankov et al. 2000), negative correlation did not depend on vegetation type of grassland. It is suggested that the ratio of C3 and C4 species is not essential for the negative correlation with temperature in summer, and water stress is more important.

6. Impact of snow depth

Snow depth in Mongolia is measured in a fenced area of about 20 m × 20 m. According to a field survey in the end of March 2004, the snow depth is obviously influenced by the fence effect and snowdrift. However, "observed snow depth" are effective for the present analysis, because interannual variability of observed snow depth must represent interannual variability of "real snow depth" around the meteorological stations.

Vegetation activity in the mature stage does not correlate with snow depth. As for the rapid growth stage, significant positive correlations between snow depth and vegetation activity in the rapid growth stage are recognized at 5 stations in forest steppe and steppe around the Khengey Mountains (Fig. 11). A long time lag of more than 4 months suggests that melting

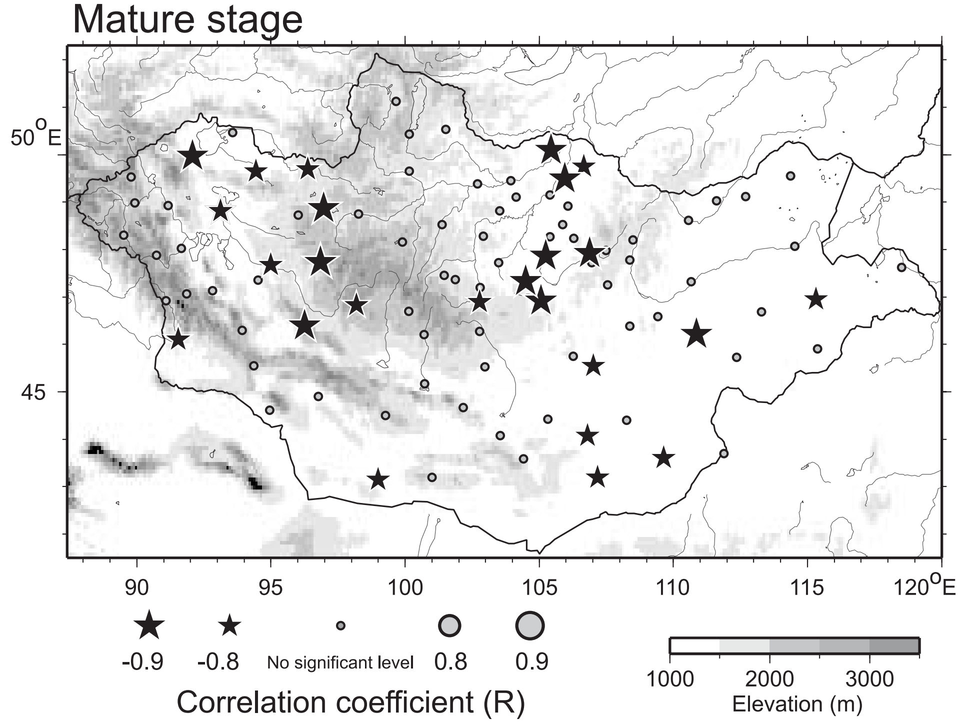


Fig. 9. Distribution of lag-correlation coefficient at the 99% significant level between air temperature in summer and vegetation activity in the mature stage.

Table 3. Number and percentage of stations with high correlation coefficients between vegetation activity in the mature stage and air temperature at the 99% and 95% significant levels.

	Number & ratio	
Vegetation type	S.L. = 99%	S.L. = 95%
Alpine vege.	2 (22%)	5 (55%)
Tiga	0 (0%)	0 (0%)
Forest steppe	6 (17%)	16 (44%)
Steppe	7 (26%)	14 (52%)
Desert steppe	8 (42%)	10 (53%)
Desert	2 (50%)	4 (100%)
Total	25 (26%)	49 (52%)

snow contributes to growth of plants at these stations.

As for two typical stations which exhibit these correlation; Baynchandmani at the western foot of the Khenty mountains (BC in Fig. 11), and Mungenmorit in the valley in the Khenty mountains (MM in Fig. 11), lag-correlation coefficients from November to February at Baynchandmani and Mungenmorit are almost over 0.9 and 0.8, respectively. Maximum lag-correlation coefficients at Baynchandmani and Mungenmorit are 0.99 in November and 0.96 in January, respectively.

In spite of high correlation at meteorological stations, correlation coefficients between snow depth and vegetation activity in surrounding pixels are 0.4–0.7. It is noted that the snow depth effect is limited to a narrow region. Baynchandmani and Mungenmorit are located in a small basin, which is confirmed by a field survey, and the range that the melting-snow water influences would be narrow, due to such a local geographical feature.

7. Prediction possibility of vegetation activity in two stages

Vegetation activity at most meteorological stations were influenced by variability of meteorological elements prior to the maximum of the vegetation activity, which indicates that

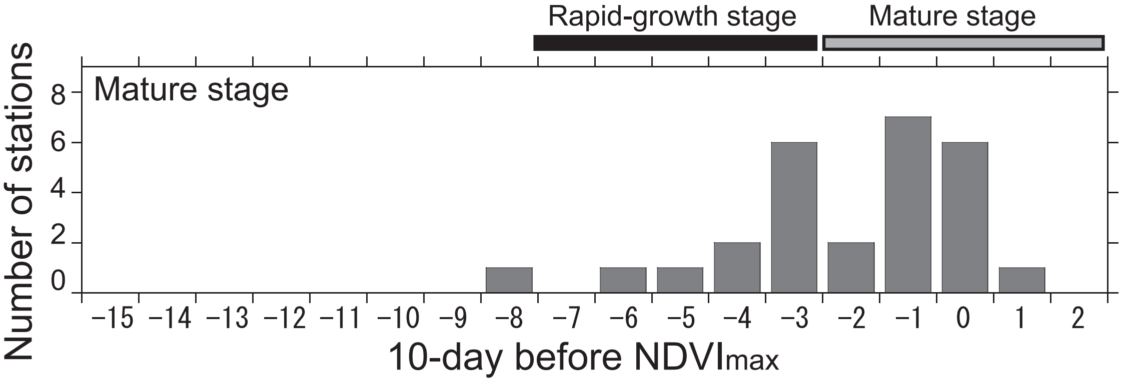


Fig. 10. Timing of the maximum lag-correlation coefficient at the 99% significant level in the mature stage relative to mean NDVI maximum.

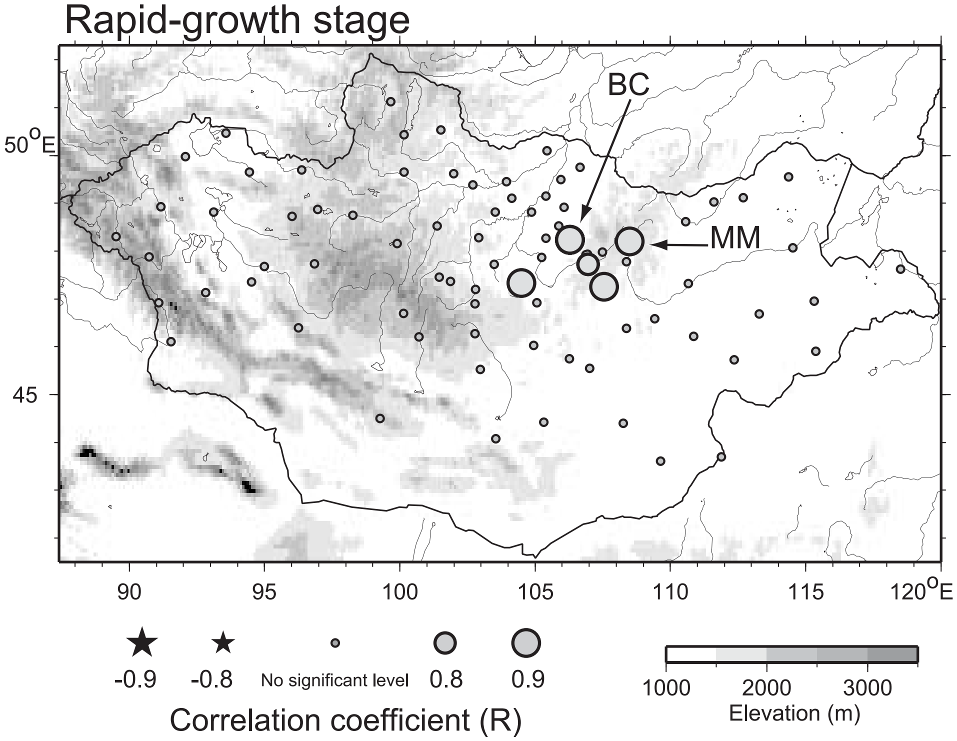


Fig. 11. Distribution of maximum lag-correlation coefficient at the 99% significant level between vegetation activity in the rapid growth stage and snow depth. Symbols of BC and MM indicate location of Baynchandmani and Mungenmorit, respectively.

the vegetation activity may be predicted using routine observation data. In this section, we examine the prediction possibility of the vegetation activity in the rapid growth stage, and the mature stage.

Multiple regression equations for the two stages are obtained by the Stepwise method for each meteorological station using monthly mean air temperature, and precipitation amount, from November to May for the rapid growth stage, and from November to June for the mature stage. Snow depth is important for some stations as shown in Fig. 11. However, snow depth was not adopted as an explanation

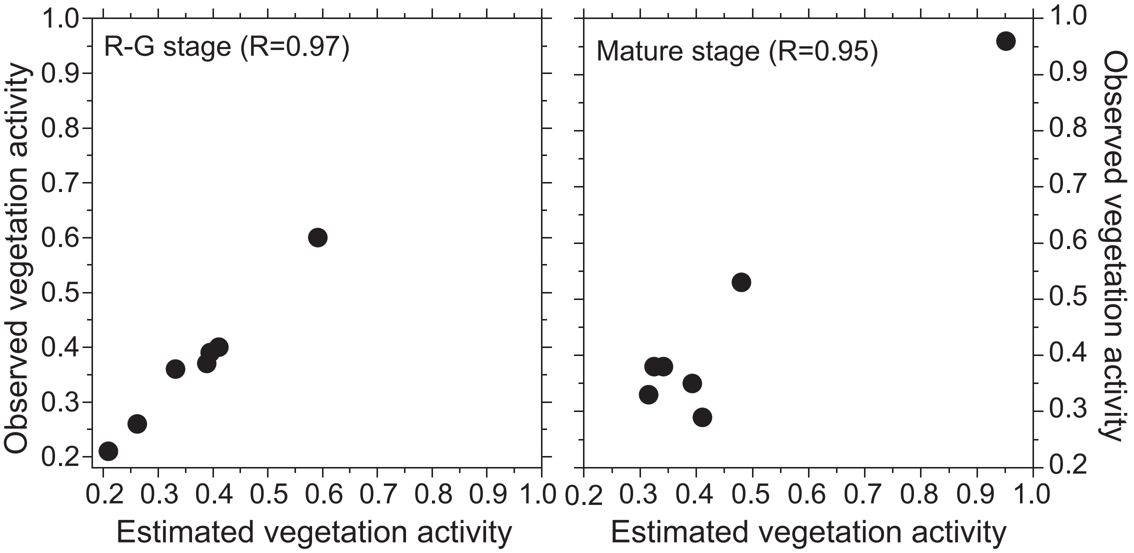


Fig. 12. Relationship between vegetation activity derived from NOAA NDVI and from multiple regression equations for the rapid growth stage (a) and the mature stage (b) at Saikhnovoo.

variable because the effect of snow depth is limited to a narrow range, and snow depth is strongly influenced by local snowdrift.

Equations (1) and (2) are multiple regression equations for Saikhanovoo (SK in Fig. 13) in desert steppe for the rapid growth stage and the mature stage, respectively. The terms of $P_{\text{-}month}$ and $T_{\text{-}month}$ indicate monthly mean precipitation (mm) and monthly mean temperature (°C), respectively. As shown in Fig. 12, correlation coefficients between observed vegetation activity and estimated vegetation activity from multiple regression equations are 0.97 and 0.94 for the rapid-growth stage, and the mature stage, respectively.

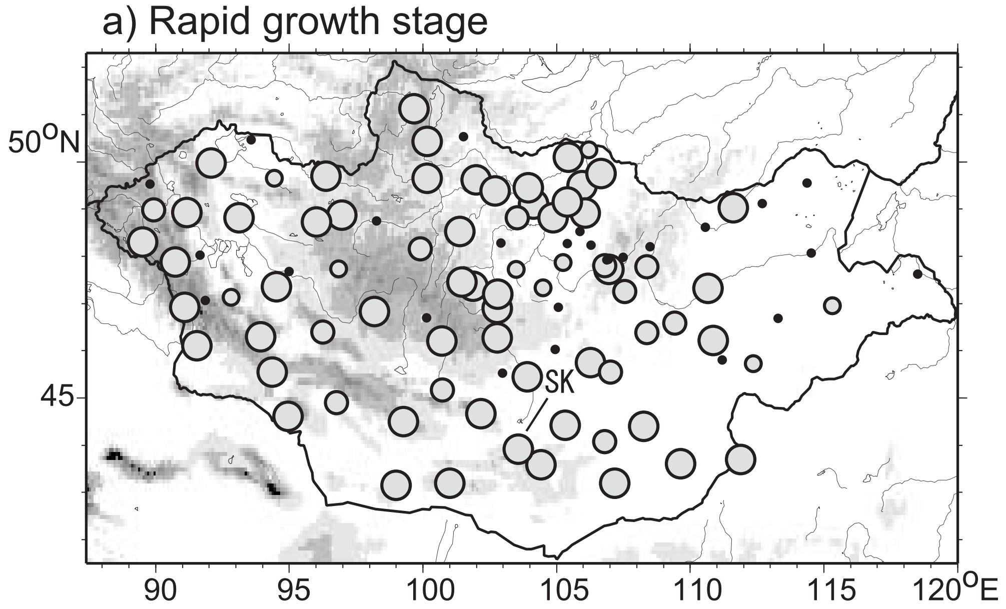
$$\begin{aligned}\text{VA\_R-G stage} = {} & -0.0968 - 0.503 * \text{P\_May} \\ & - 2.52 * \text{P\_Dec} \\ & - 0.0483 * \text{T\_Nov} \\ & - 0.0261 * \text{T\_Dec} \qquad (1)\end{aligned}$$

$$\begin{aligned}\text{VA\_M stage} = {} & -1.16 + 0.556 * \text{P\_Jun} \\ & + 0.0714 * \text{T\_Jun} \qquad (2)\end{aligned}$$

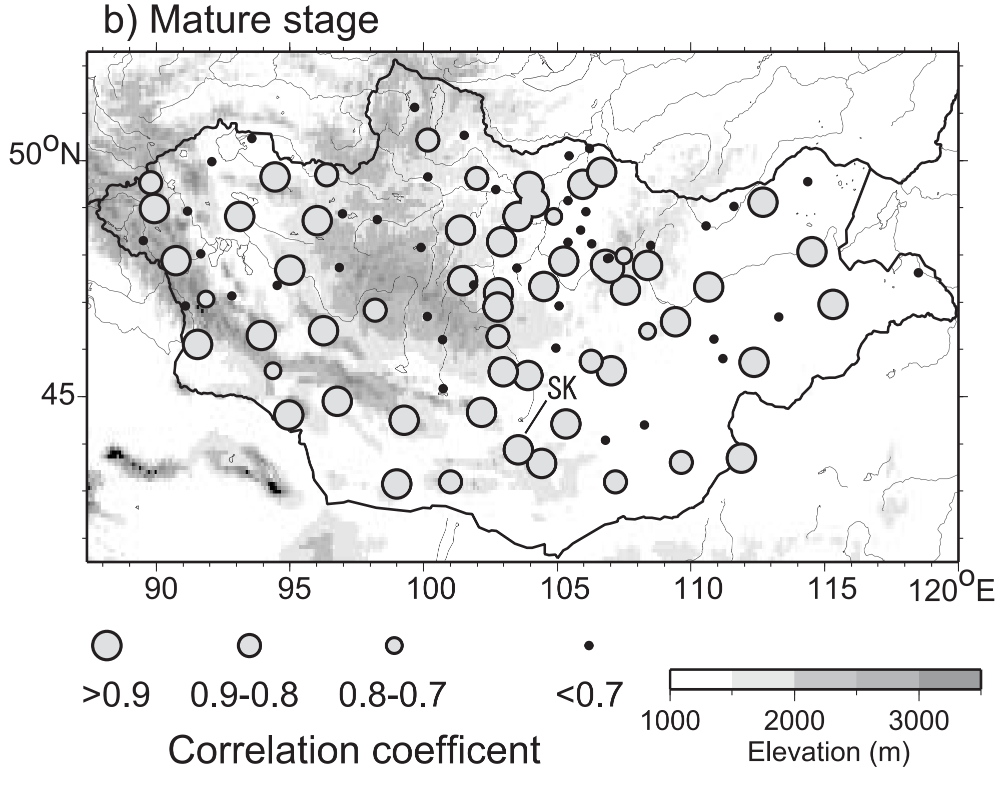
Correlation coefficient in the rapid growth stage is extremely high, even though the vegetation activity is not correlated with any 30-day averaged meteorological parameters significantly. Since contribution of precipitation and temperature in early winter are relatively large in Eq. (1), weather condition throughout the early winter might be important for the vegetation activity in the rapid growth stage at Saikhanovoo. As for the mature stage, since vegetation activity is well correlated with precipitation than the early winter temperature (Fig. 5b and Fig. 8a), contribution of the precipitation in June in Eq. (2) is larger, and terms of early winter temperature were eliminated due to the Stepwise method.

Figure 13 shows the distribution of correlation coefficients between observed vegetation activity and estimated vegetation activity from the multiple regression equations. As shown in Table 4, correlation coefficients at 73% and 58% meteorological stations for the two stages exceeds 0.7 (at about 95% significant level), and 65% and 53% stations are larger than 0.8 (at about 99% significant level). This prediction of vegetation activity would be available for these stations with high correlation. Furthermore, since correlation coefficients in desert steppe and desert are larger, this prediction method using regression equations is more effective over the drier rangelands.

Even though high correlation coefficients mean a potential for the prediction of NDVI, these regression equations do not always reflect the physical process. For example, in spite of a



a) Rapid growth stage



b) Mature stage

Fig. 13. Distribution of correlation coefficients between vegetation activity derived from NOAA NDVI and from multiple regression equations for the rapid growth stage (a) and the mature stage (b). Symbol of SK indicates location of Saikhanvoo.

Table 4. Number and percentage of stations with correlation coefficients between observed vegetation activity and estimated vegetation activity from multiple regression equations greater than 0.8 (S.L. ~ 99%) and 0.7 (S.L. ~ 95%).

	$R > 0.8$		$R > 0.7$	
Vegetation type	R-G stage	M-stage	R-G stage	M-stage
Alpine vege.	6 (66%)	5 (55%)	7 (77%)	6 (66%)
Tiga	2 (66%)	1 (33%)	2 (66%)	1 (33%)
Forest steppe	23 (64%)	15 (42%)	24 (67%)	18 (50%)
Steppe	11 (42%)	14 (53%)	18 (69%)	15 (58%)
Desert steppe	17 (89%)	12 (63%)	17 (89%)	12 (63%)
Desert	4 (100%)	4 (100%)	4 (100%)	4 (100%)
Total	63 (65%)	51 (53%)	71 (73%)	56 (58%)

large correlation coefficient in Eq. (1), there is no evidence that rainfall in December really had influenced the vegetation activity in the rapid-growth stage. It is important to investigate the physical process for full understanding of relationship between interannual variation of vegetation activity, and meteorological parameters. In addition, we also have to recalculate and verify these regression equations carefully, using more long-term data set.

8. Summary

In order to elucidate the impact of interannual variability of meteorological parameters on vegetation activity over Mongolia, the relationship between vegetation activity and meteorological parameters was analyzed. Data used in the analysis are 10-day composite NOAA AVHRR NDVI data and surface meteorological data (precipitation, air temperature and snow depth) for 97 meteorological stations from 1993 to 2000. The analysis was made on two development stages of vegetation; the rapid-growth stage and the mature stage. The mature stage is defined as the 10-day period when mean NDVI reached maximum, and includes a 20-day period before, and a 20-day period after the maximum (almost July to August). The rapid growth stage is defined as a 50-day period before the mature stage (almost June to July). The results of present analysis are summarized as follows.

1) Positive correlations at 99% significant level between precipitation and vegetation activity were recognized for 29% and 42% of meteorological stations in the rapid-growth stage and the mature stage, respectively. Precipitation in the rapid growth stage affected vegetation activity in both two stages.
2) Air temperature was not correlated with vegetation activity in the rapid growth stage. On the other hand, the impact of air temperature on vegetation activity in the mature stage was differed by season. Negative correlation between the summer temperature, and vegetation activity in the mature stage, was widely recognized. As for the winter temperature, negative correlations were found over the western and southern parts of Mongolia with respect to temperature in early winter (November to December), and positive correlations are concentrated in the northeastern part of Mongolia, with respect to midwinter (January to March).
3) There are five meteorological stations near the Khenty Mountains with high correlation coefficients between snow depth and vegetation activity in rapid growth stage. This snow depth effect is limited to a narrow region.
4) Prediction possibility of the vegetation activity in the two stages was examined using a multiple regression method. Correlation coefficients between vegetation activity derived from satellite data and estimated from multiple regression equations exceeded 0.7 for 73% and 58% of stations in the rapid growth stage and mature stage, respectively. These significant correlation coefficients mean that the prediction algorithm has a potential for the prediction of NDVI over Mongolia.

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