Impact of interannual variability of meteorological parameters on NDVI over Mongolian

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Abstract

This study is designed to elucidate the impact of interannual variability of meteorological parameters to vegetation activity over Mongolia using 10-day composite AVHRR NDVI data and surface meteorological data (precipitation, temperature and snow depth) for 97 meteorological stations from 1993 to 2000. The analysis is made on vegetation in rapid growth stage and mature stage of two development stages.

Positive correlations with 99% significant level between precipitation and vegetation activity are recognized for 30 % and 40 % of meteorological stations in rapid growth stage and mature stage, respectively. Precipitation in June to July impacts to vegetation activity in both of two stages. Impact of air temperature to vegetation activity is different by a season. Negative correlations between summer temperature and vegetation activity in a mature stage are recognized wildly. As for imact to vegetation activity in a rapid growth stage, 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 in midwinter. There are five meteorological stations near the Henty mountains with high correlation coefficient between snow depth and vegetation activity in rapid growth stage, however, the snow depth effect is limited to a narrow region.

Prediction possibility of the vegetation activities in two stages is examined using multiple regression method based on above-mentioned results, and the prediction algorithm would be available for more than half of stations over Mongolia.

1. Introduction

Mongolia is located in the vegetation transition zone, and the vegetation ranges from tiga forest in the north to desert in the south. Rangeland in Mongolia with 1.26 x 10^6 km^2 occupies 97% of the country, which is classified into five subtypes; high mountains (4.5%), forest steppe (22.9%), steppe (28.0%), desert steppe (28.4%) and desert (16.2%) (Bolortsetseg et al. 2000). These rangelands are main source of forage for nomadic livestock, so that, productivity of a grass in the rangeland gives their life direct influence. Since a warming trend in winter months is larger in the recent 40-60 years (Yatagai and Yasunari, 19**; Natsagdorj, 2000), the annual precipitation has exhibited an slightly increasing trend in most area except for the desert area and the spring dryness has occurred during the last 60 years (Natsagdorj, 2000), climate change is expected to have a large impact on nomad and agriculture. Knowledge on a possible impact of climate change on productivity of rangeland is important for Mongolian society.

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

Another is the study on the impact of anomaly of the meteorological parameters to NDVI anomaly, and the present 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 region (Schultz and Halpert, 1995). On the other hand, negative correlation was recognized mainly in mid-latitude including some parts of Mongolia (Nemani et al., 1993; Schultz and Halpert, 1993; 1995). Anomaly of rainfall and NDVI are 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 rainfall anomaly preceded NDVI anomaly by about 0-1 month around the African Sahel. Positive lag correlation also recognized between NDVI anomaly and 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 set which are not suitable to elucidate the features of regional scale, it is necessary to re-examine using data of meteorological stations over Mongolia. Further, a lot of observation data make quality of analysis improve. 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 the central Mongolia. However, there is few studies on the relationship between vegetation activity and meteorological elements over the whole Mongolia. A purpose of this study is to describe on the impact of interannual and seasonal variability of precipitation, air temperature and snow depth on NDVI over Mongolia using data of a lot of meteorological stations. Further, the prediction possibility of vegetation activity will be examine based on results of the analysis.

2. Data and analysis methord

2.1 Description on the data set

Data used in the present analysis are 10-day composite AVHRR NDVI data set provided by Center for Environmental Remote Sensing, Chiba University, and surface meteorological data set provided by Institute of Meteorology and Hydology, Mongolia. Original spatial resolution of NDVI data is about 8 km, and high-frequency noises in original AVHRR NDVI were removed using temporal window operation method (Park et al., 1999).

A surface meteorological data set contains 3-hourly air temperature, twice-daily precipitation (9 and 21 LST) and daily snow depth from 1993 to 2000 for 97 stations (Fig. 1). These raw data were edited in 30-day mean value every 10 days.

2.2 Classification of vegetation type and some features of NDVI over the Mongolia

Vegetation in Mongolia are 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 of other stations was defined using a map of vegetation distribution of Hilbig (1995). Stations in typical grassland of forest steppe, steppe and desert steppe, which are suitable source of forage for livestock, occupied about 83 % (see Fig. 1 and Table 1).

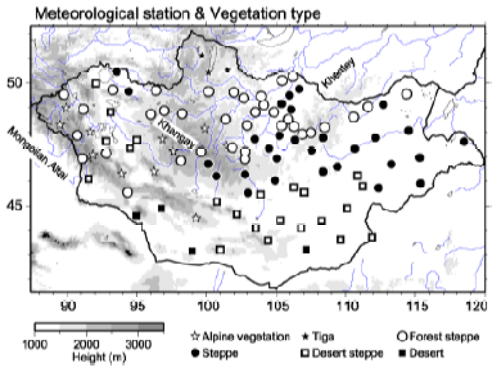


Fig. 1: Distribution of meteorological stations with vegetation type. The six meteorological stations that was not used for analysis is also plotted.

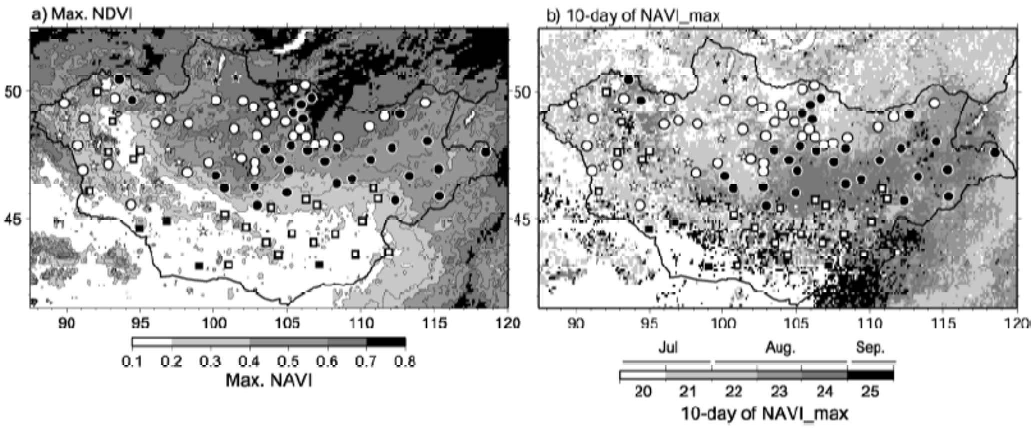


Fig. 2: Distribution of the maximum value of mean NDVI (a) and the time when the mean NDVI reaches maximum value (b). Location of meteorological station is indicated by a mark same to Figure 1.

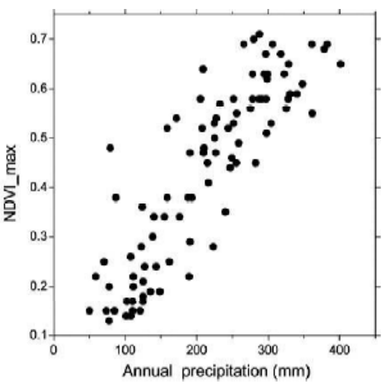


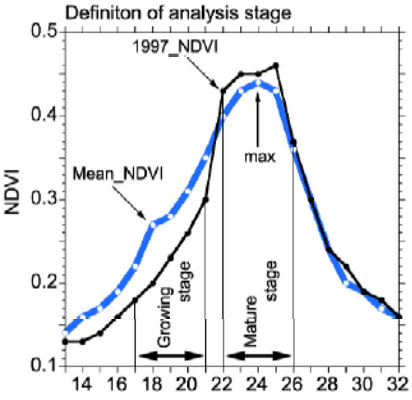
Figure 3: Relationship between annual precipitation and maximum NDVI in Mongolia.

Figure 2 shows distribution of the maximum value of mean NDVI and phase of seasonal variation of mean NDVI. As shown in Fig. 2a, maximum value is 0.6-0.7 in the northern Mongolia corresponding to forest region, and it decreases gradually from north to south. Maximum value lower than 0.2 in the southern Mongolia and region between Mongolian Altai and Khangay mountains are almost corresponding to desert steppe and desert. Distribution pattern of maximum NDVI is similar to that of annual precipitation (not shown), and maximum NDVI are well correlated with annual precipitation (Fig. 3). As shown in Fig. 2b, the time when mean NDVI reaches a maximum are varied from the middle of July to the beginning of September. It is noted that the mean NDVI around steppe vegetation tend to reach a maximum at the middle to the end of August, which is 10 to 30 days later than both of forest steppe and desert steppe.

2.3 Definition of two development stages and vegetation activity

In this analysis, impact of interannual variability of meteorological parameters on NDVI will be investigated for each meteorological station in two growth stages; rapid growth stage and mature stage. However, the time when mean NDVI reaches a maximum is different greatly by a place as shown in Fig. 2b, which means that phase of development stage of plants is also different greatly by a place. The development stage of plants should be defined every meteorological station.

Figure 4 shows the seasonal variation of 8-year mean NDVI and NDVI in 1997 at a station in steppe. Mature stage is define as the period of the 10-day when mean NDVI reached maximum, 20-day before the maximum and 20-day after maximum; from 22 to 26 in 10-day in this station. Rapid growth stage is defined as the period before 50 days of mature stage.



Vegetation activities for each year in rapid growth stage and mature stage are defined as the sum of NDVI value in each stage, respectively. Since NDVI in spare vegetation region have considerable 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 rapid growth stage over the spare vegetation in the south Mongolia would have contamination in some degrees.

There are no data from the end of September to December in 1984. As for this period, 8-year mean NDVI value are substituted for the missing data. This process does not influence the results.

Fig. 4: Definition of the rapid growth stage (R-G stage) and mature stage of vegetation activity

2.4 Calculation of correlation coefficient

Meteorological parameters are averaged in 30-day for every 10-day, and 36 mean values were obtained for one parameter and one year. There are many "no observation" in the data set, especially in snow depth data around the beginning and end of snow season. These data are treated as missing values. When the missing value less than 10%, correlation coefficients in two stage were calculated for all combination.

An analysis period is short with 8 years. Since number of data using calculation of correlation coefficient is 8 at most, correlation coefficient with less than 99% confidence level were neglected basically in this analysis.

3. Impact of precipitation

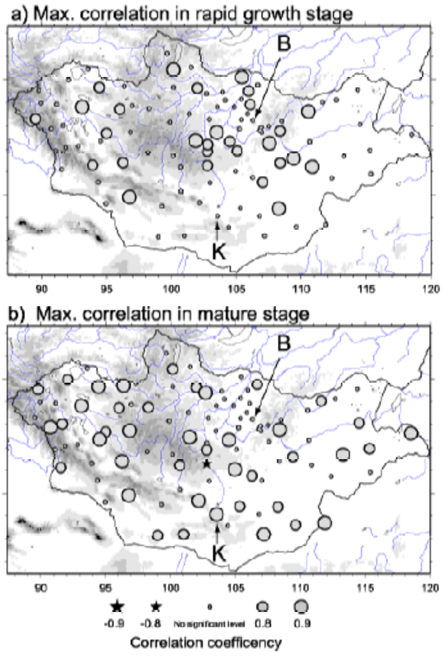
Figure 5 shows distribution of the maximum correlation coefficient between precipitation and vegetation activity in two stages. Positive correlations with 99% significant level are recognized at 29 % of all stations in rapid growth stage (Fig. 5a), and the ratio increases to 42 % in mature stage (Fig.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

As shown in Table 1, there is a lot of stations with significant positive correlation in steppe (42 %) with low annual precipitation than forest steppe (19 %) with high annual precipitation in rapid growth stage. However, the ratio in desert steppe and desert are extremely low in the rapid growth stage (Table 1). There is a possibility that estimation error of NDVI in the rapid growth stage due to spare vegetation decreases the correlation coefficient.

In mature stage, significant correlation were recognized at 25 % of all station 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 at vegetation zone with a 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).

Timing of maximum correlation is different by station. Figure 6 shows timing of the maximum correlation coefficient relative to the time when mean NDVI reaches a maximum; "0" in the x-axis means time of the maximum of mean NDVI. When a station had two maxima, these two maxima were counted in Fig. 6. Precipitation in early rapid growth stage had impacted on the vegetation activity in rapid growth stage, and there is not a large time lag. On the other hand, precipitation in mature stage did not almost influence on the vegetation activity in mature stage. Precipitation before 1-2 months of the mature stage had impacted on the vegetation activity in mature stage, which is consistent with the results of the previous studies (Schultz and Halpert, 1995; Miyazaki e al., 2004). In other word, precipitation in rapid growth stage is importance for vegetation activity in both of two stages.

Precipitation before 4-5 months of mean NDVI maximum (April to May) were correlated with vegetation activities in some meteorological stations in Fig. 6. These stations are located between Mongolian Altai and Khangay mountains.



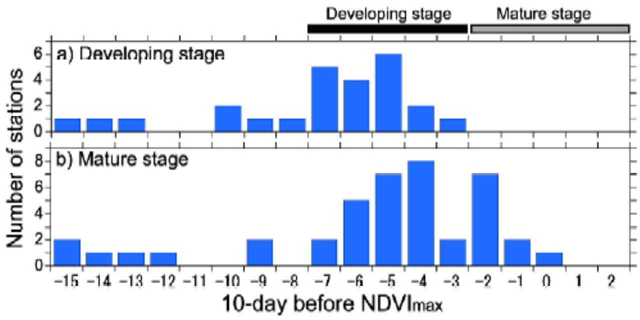


Fig. 5: Distribution of correlation coefficient between precipitation amount and NDVI in a rapid growth stage and a mature stage.

Fig. 6: Timing of the maximum correlation coefficient relative to mean NDVI maximum in rapid growth stage (a) and mature stage (b). One station with significant negative correlation in mature stage in Fig. 4b is not counted.

Table 1: Number and percentage of stations with significant correlation coefficient between vegetation activities and precipitation for rapid growth stage (R-G stage) and mature stage.

	R-G stage	Mature 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

4. Impact of air temperature

Some previous studies used ground temperature estimated from satellite IR data. The data set used in he 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 correlation coefficients are is apparently lower than that of air temperature. Therefore, we will focus on air temperature.

4.1 Impact of temperature to rapid growth stage

There are several stations with significant correlation between vegetation activity in rapid growth stage and air temperature, however, apparent regularity nor systematic distribution could not be found.

4.2 Impact of winter temperature to mature stage

Figure 7 shows maximum correlation coefficient with 95% significant level from October to December (early winter) and January to March (midwinter). Correlations on winter temperature are no so clear that 95% significant level was adopted in only this analysis. Features are completely different in the early winter and the midwinter. Negative correlations are recognized in the western Mongolia, and there are less correlation in steppe (Table 2). As for impact of midwinter air temperature, correlation coefficient more than 0.8 are concentrated in forest steppe and steppe in the northeastern part of Mongolia, and no significant correlation are found over the drier regions (Table 2).

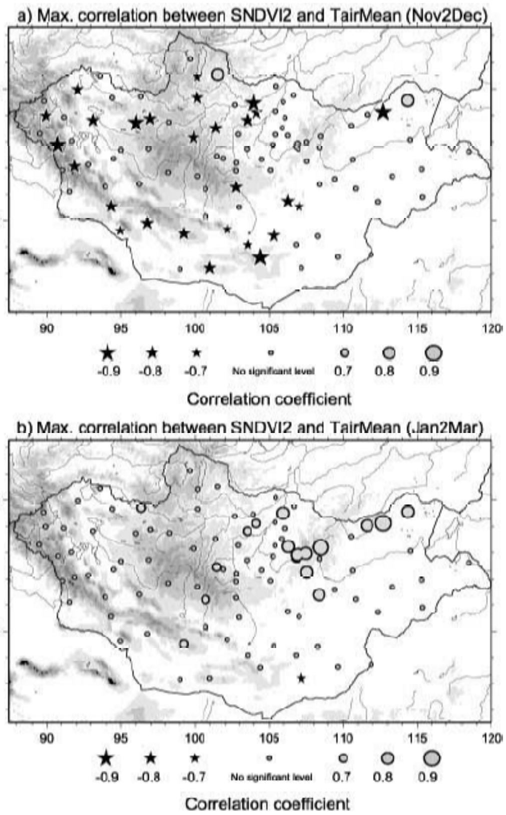


Fig. 7: Distribution of maximum correlation coefficient with 95 % significant level between vegetation activity in mature stage and air temperature from November to December (a: early winter) and from January to March (b: midwinter).

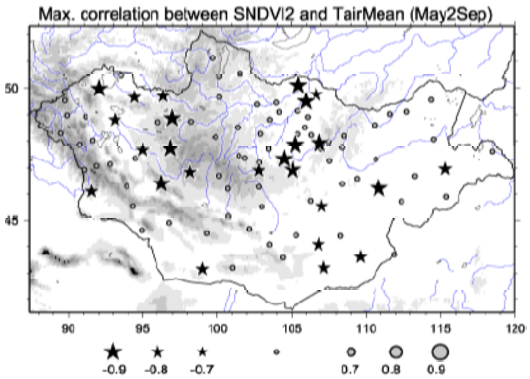
Table 2: Number and percentage of stations with significant negative correlation coefficient between vegetation activity in mature stage and air temperature in the early winter and midwinter. Two positive correlations in Fig. 7a and a negative correlation in Fig. 7b are not counted.

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%)

4.2 Impact of summer temperature to mature stage

Figure 8 shows the maximum correlation coefficient with 99 % significant level from May to September. Significant negative correlation are recognized at 26 % of all stations in mature stage (Fig. 8 and Table 2). As shown in Fig. 9, high temperature in mature stage had impacted on vegetation activity in mature stage, and these features are consistent with the results of Miyazaki et al. (2004).

Table 3 shows number and ratio of stations with significant correlation. As for grasslands, their correlation coefficients are 17-26% at 99% significant level, and 44-53% at 95% significant level, respectively. There is no clear difference among grasslands on the impact of air temperature. It is noted that although percentage of C4 species, which have advantage for 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 ratio C3 and C4 species is not essential for the negative correlation with temperature in summer, and water stress is more important.



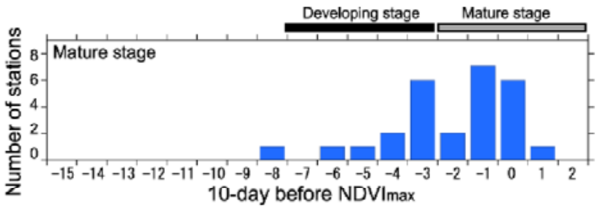


Fig. 8: Distribution of significant correlation coefficient at 99% significant level between air temperature in summer and vegetation activity in a mature stage.

Fig. 9: Timing of the maximum correlation coefficient with 99% significant level in mature stage relative to mean NDVI maximum.

Table 3: Number and percentage of stations with correlation coefficient between vegetation activity in mature stage and air temperature more than 99% and 95% significant level.

Vegetation type	Number & ratio	
	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%)

5. Impact of snow depth

Snow depth in Mongolia is measured in fenced area of about 20m x 20m. 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 snow depth must represent interannual variability of "real snow depth" around meteorological station.

Vegetation activity in mature stage does not correlate with snow depth. As for rapid growth stage, significant positive correlation between snow depth and vegetation activity in rapid growth stage are recognized at 5 stations in forest steppe and steppe around Hengey mountains. Long time lag of more than 4 months suggests that melting snow contributes to growth of plants in these stations.

There are two typical stations of Baynchandmani in the western foot of the Khenty mountains (B in Fig. 10) and Mungenmorit in the valley in the Khenty mountains (M in Fig. 10). Correlation coefficients from November to February at Baynchandmani and Mungenmorit are almost over 0.9 and 0.8, respectively. Maximum correlation coefficients at Baynchandmani and Mungenmorit are 0.99 in November and 0.96 in

January, respectively.

In spite of high correlation in meteorological stations, correlation coefficients between snow depth and vegetation activity surrounding pixcels 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 the small basin, which are confirmed by a field survey, and the range that the melting-snow water influences would be narrow due to such local geographical feature.

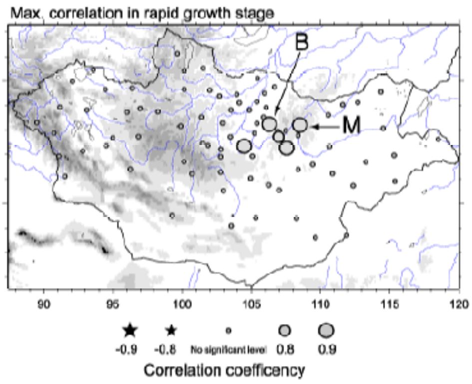


Fig. 10: Distribution of maximum correlation coefficient between vegetation activity in rapid growth stage and snow depth. Symbols of B and M indicate location of Baynchandmani and Mungenmorit, respectively.

6. Prediction possibility of vegetation activity in two stages

Vegetation activities in most of meteorological stations were influenced by variation of meteorological elements before a few to several months, which indicates that the vegetation activity may be predicted using routine observation data. In this section, we examine the prediction possibility of the vegetation activities in rapid growth stage and mature stage.

Multiple regression equations for 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 rapid growth stage, and from November to June for mature stage. Snow depth is important for some stations as shown in Fig. 9 and 10. However, snow depth was not adopted as an explanation variable because the effect of snow depth is limited to a narrow range and snow depth is influenced by local snowdrift strongly.

Equations (1) and (2) are multiple regression equations of Mandalgovi (MG in Fig. 11) in desert steppe for rapid growth stage and mature stage, respectively. Terms of P_*month* and T_*month* mean monthly mean precipitation (mm) and monthly mean temperature (°C), respectively. Correlation coefficients between observed vegetation activity and estimated vegetation activity from multiple regression equations are more than 0.95 for two stage.

$$VA_{R\text{-}G\ stage} = -1.45 + 0.0214*P_{May} + 0.117*T_{Oct} - 0.0869*T_{Nov} - 0.0710*T_{Dec} \quad \text{---} \ (1)$$

$$VA_{matur\ stage} = -0.0702 + 0.0380*P_{Apr} - 0.0398*T_{Jun} - 0.109*T_{Nov} - 0.109*T_{Dec} \quad \text{---} \ (2)$$

Figure 11 shows distribution of correlation coefficients between observed vegetation activity and estimated vegetation activity from multiule regression equations. As shown in Table 4, correlation coefficients of 73 % and 58 % meteorological stations for two stages exceeds 0.7 (about 95 % significant level), and 65 % and 53 % stations are larger than 0.8 (about 99 % significant level). This prediction on vegetation activity would be available for these stations with high correlation. Further, since correlation coefficients in desert steppe and desert are larger, this prediction method is more effective over the drier rangelands.

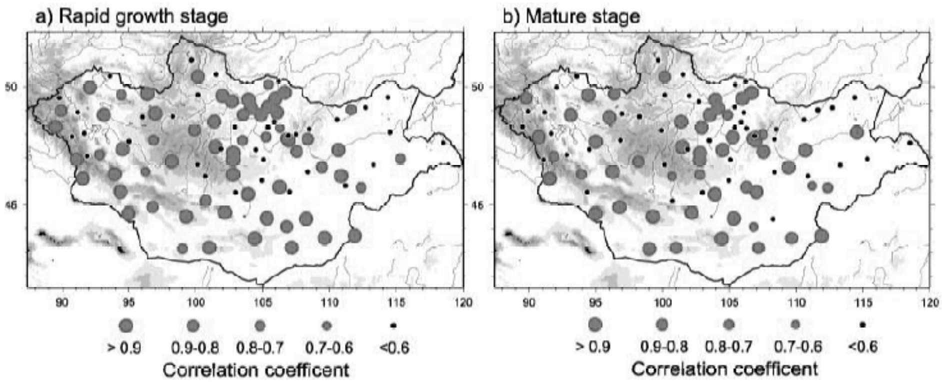


Figure 11: Distribution of correlation coefficients between activity derived from NOAA NDVI and from multiple regression equations for rapid growth stage (a) and mature stage (b).

Table 4: Number and percentage of stations with correlation coefficient between observed vegetation activity and estimated vegetation activity from multiple regression equations more than 0.80 and 0.70.

	R>0.80		R>0.70	
Vegetation type	R-G stage	Mature stage	R-G stage	Mature 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%)

7. Summary

In order to elucidate the impact of interannual variability of meteorological parameters on vegetation activity over Mongolia, relationship between vegetation activity and meteorological parameters was analyzed. Data used in the analysis are 10-day composite 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; rapid growth stage and mature stage. Mature stage is define as the period of the 10-day when mean NDVI reached maximum, 20-day before and 20-day after the maximum. Rapid growth stage is defined as the period before 50 days of mature stage. The results of present analysis are summarized as follows.

1. Positive correlations with 99% significant level between precipitation and vegetation activity were recognized for 29 % and 42 % of meteorological stations in rapid growth stage and mature stage, respectively. Precipitation in rapid growth stage (June to July) had impacted into vegetation activity in both of rapid growth stage and mature stage.

2. Air temperature were not correlated with to vegetation activity in rapid growth stage. On the other hand,

impact of temperature to vegetation activity was different by a season. Negative correlation with 99% significant level between summer temperature (June to August) and vegetation activity in mature stage was recognized wildly. As for the rapid growth stage, negative correlations with 95 % significant level were found over the western part of Mongolia with respect to temperature in early winter (November to December), and positive correlations with 95 % significant level are concentrated in the northeastern part of Mongolia with respect to in midwinter (January to March).

3. There are five meteorological stations near the Henty mountains with high correlation coefficient 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 activities in two stages was examined using multiple regression method. Correlation coefficients between vegetation activities derived from satellite data and estimated from multiple regression equations exceeded 0.70 for 73 % and 58 % of stations in rapid growth stage and mature stage, respectively. Prediction algorithm based on multiple regression equations would be available for more than half of stations over Mongolia.

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