Impact of interannual variability of meteorological parameters on vegetation activity and predict possibility of vegetation activity over Mongolia

IWASAKI Hiroyuki[1]

[1] Faculty of Education, Gunma University, Maebashi, Japan

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I Introduction

Mongolia is located in 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 occupies 97% of the country. 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. 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 deserts, 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 impact of climate change on productivity of the rangelands is important for Mongolian society.

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 (*e.g.* Samuel and Prince, 1995; Schultz and Halpert, 1995; Potter *et al*. 1988).

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 the 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 impact of interannual and seasonal variability of precipitation, air temperature 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.

II Data and analysis methord

1. Description of the data set

Data used in the present analysis are 10-day composite NDVI data, and surface meteorological data set provided by the Institute of Meteorology and Hydology, Mongolia.

The surface meteorological data set contains 3-hourly air temperature, twice-daily precipitation (9 and 21 LST) from 1993 to 2000 for 97 stations (See Fig. 2). There are more than a few "no observation" values in the data set. These data are treated as missing values. Meteorological parameters are averaged in 30-day intervals for every 10-day period, if the missing values were less than 10% in the 30-day interval.

2. 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 developmental stages; the rapid growth stage and the mature stage. However, the time when mean NDVI reaches a maximum differs greatly by location, which means that the phase of development stage of plants also differs greatly by location. The developmental stage of plants should be defined at every meteorological station.

Fig. 1 shows the seasonal variation of 8-year mean NDVI and NDVI in 1997 at a station in steppe vegetation. Mean NDVI reached a maximum at the end of August (the 24th 10-day period), and the maximum value will be referred to as $NDVI_{max}$. The mature stage is defined as the 10-day period when mean NDVI reached maximum, as well as 20-day period prior to the maximum and the 20-day period after maximum. The 22nd to 26th 10-day period is the mature stage for this station. The rapid-growth stage is defined as before 50-day period before the mature stage; from 17th to 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. Since NDVI in sparse vegetation region have considerable errors due to the influence of the reflectance of background soil, 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 degrees.

There are no data from the end of September to December in 1984. As for this period, 7-year mean NDVI value are substituted for the missing data. This process does not influence the results.

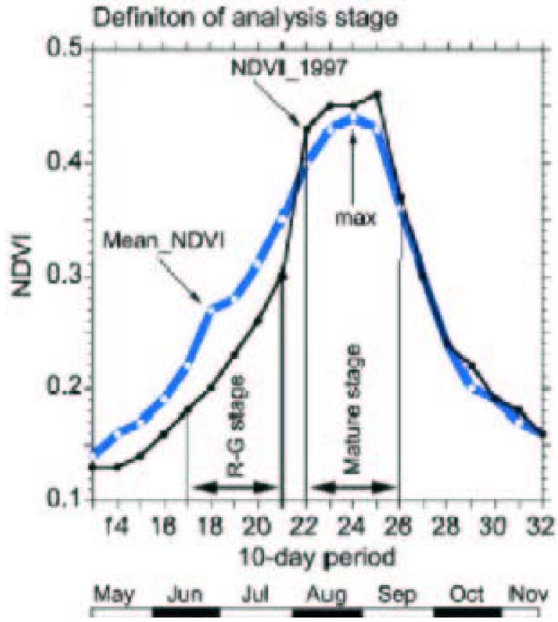

Fig. 1 Definition of the rapid-growth stage (R-G stage) and the mature stage of vegetation activity.

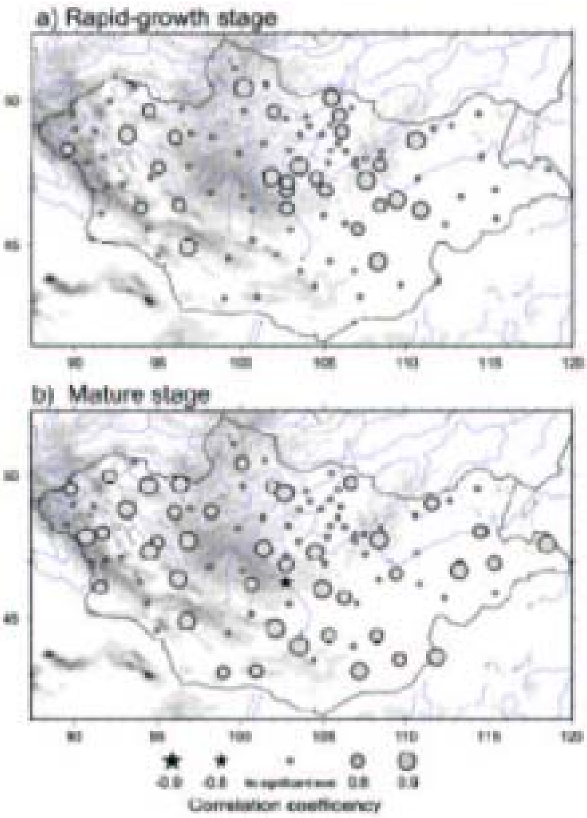

Fig. 2 Distribution of the correlation coefficient between precipitation amount and NDVI in the rapid-growth stage and the mature stage.

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 correlation coefficients between meteorological parameters and vegetation activity in the two stages are calculated for all combinations. The maximum value among these correlation coefficients will be discussed in this paper.

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% confidence level were neglected in this analysis.

III Impact of precipitation

Fig. 2 shows distribution of the maximum correlation coefficient between precipitation and vegetation activity in the two stages. Positive correlations at the 99% significant level are recognized at 29% of all stations in the rapid growth stage (Fig. 2a), and increases to 42% in the mature stage (Fig. 2b). 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.

Although there are number of stations with significant positive 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.

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.

Timing of the maximum correlation differs by station. Fig. 3 shows the timing of the maximum correlation coefficient 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. 3. 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 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. In other word, precipitation in the rapid growth stage is importance for vegetation activity in both two stages.

Precipitation 4-5 months before the mean NDVI maximum (April to May) were correlated with vegetation activities in some meteorological stations in Fig. 3. These stations are located between Mongolian Altai and the Khangay Mountains.

IV Impact of air temperature

1. Impact of air temperature to vegetation activity in the rapid-growth stage

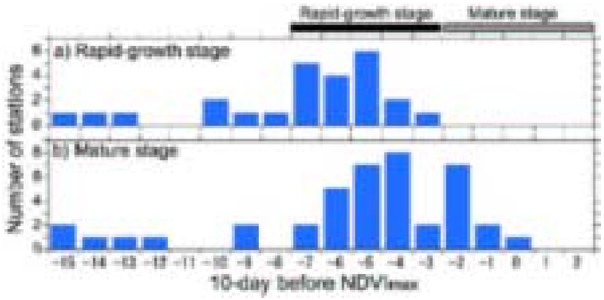

Fig. 3 Timing of the maximum correlation coefficient relative to mean NDVI maximum in the rapid-growth stage (a) and the mature stage (b).

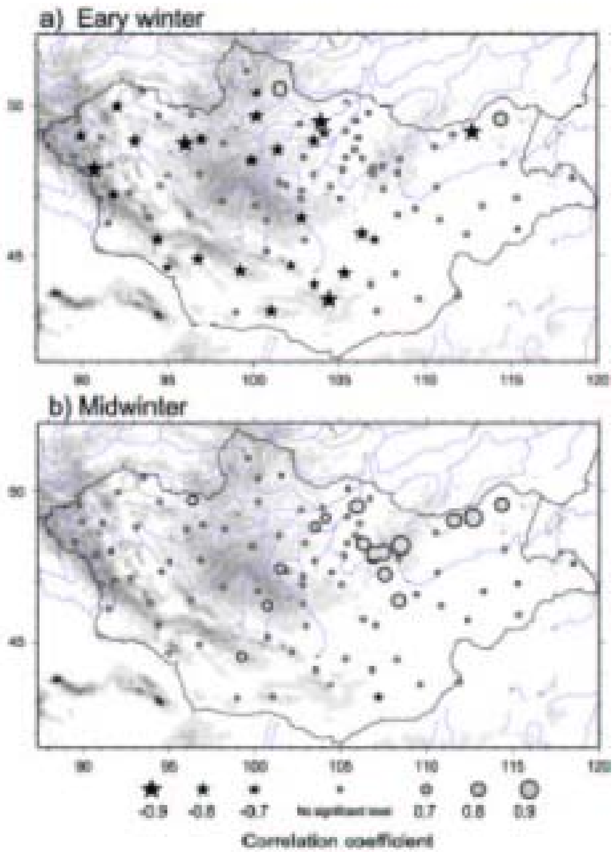

Fig. 4 Distribution of max. correlation coefficient at the 95% significant level between vegetation activity in the mature stage and air temperature from Nov. to Dec. (a: early winter) and from Jan. to Mar. (b: midwinter).

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.

2. Impact of winter temperature to vegetation activity in the mature stage

Fig. 4 shows the maximum correlation coefficient at the 95% significant level from October to December (early winter) and 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 the midwinter. Negative correlations are recognized with respect to the early winter temperature in western and southern Mongolia, and there are fewer correlations in steppe. 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.

3. Impact of summer temperature to vegetation activity in the mature stage

Fig. 5 shows the maximum correlation coefficient at the 99% significant level from May to September. Significant negative correlations are recognized at 26% of all stations in the mature stage. Higher temperature in the mature stage impacted vegetation activity in the mature stage.

V 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 activity, which indicates that 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.

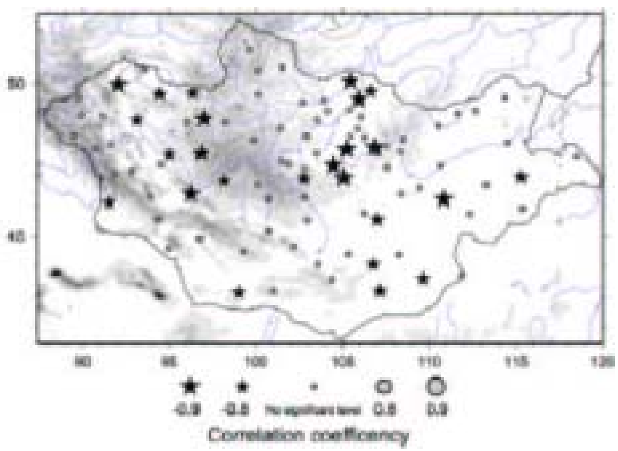

Fig. 5 Distribution of significant correlation coefficient at the 99% significant level between air temperature in summer and vegetation activity in the mature stage.

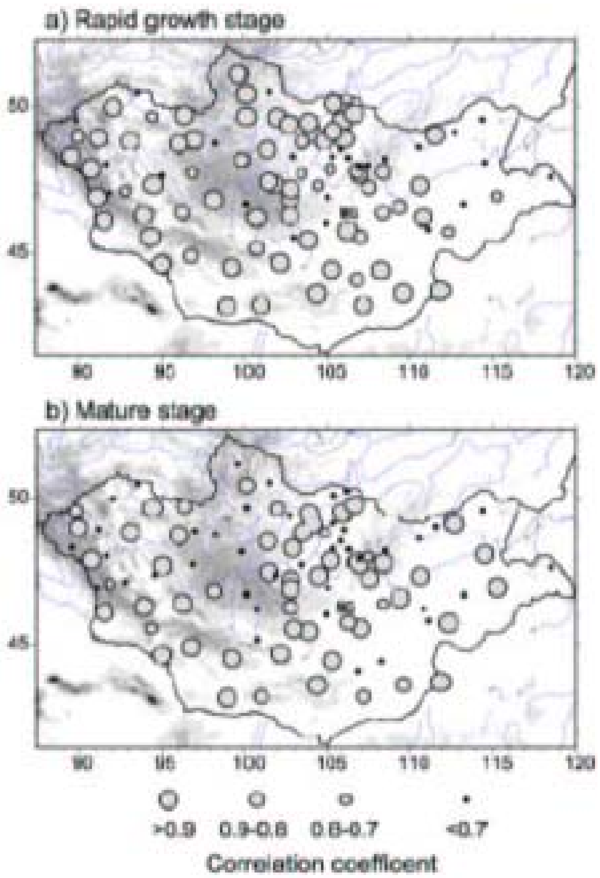

Fig. 6 Distribution of correlation coefficients between vegetation activity derived from NOAA NDVI and from multiple regression equations for the rapid growth stage (a) and the mature stage (b).

Fig. 6 shows the distribution of correlation coefficients between observed vegetation activity and estimated vegetation activity from the multiple regression equations. Correlation coefficients at 73% and 58% meteorological stations for the two stages exceeds 0.7 (about at 95% significant level), and 65% and 53% stations are larger than 0.8 (about at 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 is more effective over the drier rangelands.

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