=== ДОКЛАДЫ ===

ИНДЕКСЫ NDVI И LST ПРЕДСТАВЛЕННЫЕ NOAA-AVHRR ДЛЯ ВЫЯВЛЕНИЯ ЗАСУХ В МОНГОЛИИ

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Временно-пространственные колебания нормализованного разностного вегетационного индекса NDVI, температуры поверхности земли LST получены NOAA – AVNRR датчиками в течение вегетационного периода; определена динамика накопления фитомассы растительности. Опыты проведены в 1992-1999 гг. и проанализированы в экосистемах полупустынь и пустынь Монголии. Высокая негативная связь между NDVI и LST дает возможность общего комплексного использования этих переменных для контроля над параметрами засухи. Было проведено сравнение между двумя указателями NDVI. Проанализировано отношение между LST и NDVI (LST/NDVI), в результате чего, выявлены функционирования разных пространственных моделей при неодинаковом ускорении режимов. Более того, различия были обнаружены между индексами и традиционно обоснованными данными метеорологических наблюдений.

NOAA-AVHRR DERIVED NDVI AND LST FOR DETECTING DROUGHTS IN MONGOLIA

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Introduction

Satellite-derived early warning of droughts and assessing their severity are becoming popular in wide-ranging disaster monitoring and climate change studies. Though drought is a complex phenomenon, it has been defined by the meteorological community as a period of abnormally dry weather, which results in decrease of vegetation cover (Tucker & Choudhury, 1987; Heim, 2002). Drought can be ended when a region receives necessary amount of precipitation in a certain period (e.g., weeks, months), and thus the decreased vegetation cover might be recovered (Nicholson et al., 1998; Prince et al., 1998). Therefore, start, end and the effect of drought on the vegetation in wide areas can be estimated by monitoring the dynamics of vegetation cover over time by using remote sensing change detection method.

Numerous researchers investigated the possibility of assessing and monitoring droughts in semi-arid environments (e.g., Gutman, 1990; McVicar & Jupp, 1998) using indices derived from Advanced Very High Resolution Radiometer (AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA) satellites. The sensor has been orbiting around the globe since the late 70th with 5 spectral channels. The sensor's data (1981-present) is archived and distributed by the National Aeronautics and Space Administration (NASA). In the past-decades, the Normalized Difference Vegetation Index (NDVI, Tucker, 1979) calculated from the reflected channels of the NOAA-AVHRR were developed and successfully used for assessing droughts (Tucker & Choudhury, 1987). Moreover, several authors used the ratio between the NDVI and land surface temperature (LST/NDVI) in order to improve estimation of vegetation state and condition with respect to droughts or stress situations (McVicar & Bierwith, 2001; Karnieli & Dall'Olmo, 2003; Bayarjargal et al., 2000). The reason for using the combined NDVI and LST data is based on their strong negative correlations in the arid environment and the hypothesis that increasing temperatures are acting negatively on vegetation vigor and consequently are causing stress (Nemani & Running, 1989; Lambin & Ehrlich, 1996; Karnieli et al, 2005).

The aims of this paper are to study the spatial-temporal variations of the NDVI and LST and to compare the effectiveness of the spaceborne drought-indices during the growing period over the Desert-Steppe and Desert ecosystems of Mongolia, also with respect to the traditional ground-observed weather data.

Study area and dataset

The research objective was implemented on the Mongolia's Desert-Steppe and Desert ecosystems that cover more than 40% of the country (Appendix 4, Figure 1). The study area includes the Great Lakes Depression, the Valley of Lakes, the Gobi-Altai Mountains, and the Plateau of Eastern Gobi. Low grasses, semi-shrubs, and woody plánts are the dominant vegetation of the study area, and peak biomass occurs in the late summer (Batima et al., 2000). The annual mean air temperature is about 4°C. July is the warmest month with average temperature of 25°C and maximum temperature can reach 35-45°C (Natsagdorj, 2000). The total annual precipitation is about 75-150 mm and less than 75 mm in the Desert-Steppe and Desert ecosystems, respectively. About 75-85% of the precipitation falls during the three summer months, from June to August. It was reported that the frequency of drought in the Gobi region during the spring and summer has been increased from 1-2 to 3-4 times every five years (Shiirevdamba, 1999). Thus, the Desert-Steppe and Desert ecosystems of Mongolia were chosen as test area for studying the spatial-temporal variations of the NOAA-AVHRR derived NDVI and LST, and for comparing their effectiveness in drought detection.

The Pathfinder AVHRR Land (PAL) archived NDVI and brightness temperatures in channel 4 and channel 5 were used in this study. The LST was computed from the brightness temperatures by split-window algorithm (Price, 1984; Qin and Karnieli, 1999). Dataset were composed of monthly maximum values for vegetation growing season (April-September) over the period of 1982-1999, in the Geographical projection with spatial resolution of 0.1 x 0.1 degrees in latitude and longitude. The PAL dataset was generated from the NOAA satellite 7, 9, 11, and 14 (Agbu & James, 1994) and was obtained from the Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC, WWW). The PAL dataset were used for many studies of global vegetation (e.g., Shabanov et al., 2002; Buermann et al., 2002), and changes in land cover characteristics (e.g., Anyamba and Eastman, 1996; Young and Wang, 2001; Henebry, 2004; Lioubimtseva, 2004; and more).

Analysis

This study intends to evaluate inter-annual variations and spatial distributions of NOAA-AVHRR derived NDVI and LST over the Desert-Steppe and Desert ecosystems of Mongolia, during 18-year period. Data processing was limited to the vegetation-growing period (VGP) that lasts for 6 months from April to September, since only the warm-summer season allows vegetation development in the region after the harsh winter. The VGP was divided into three sub-periods of phenology: the beginning (April-May); the middle (June-July); and the end (August-September).

The change detection technique – Change Vector Analysis (CVA) – that was adapted to the multi-temporal space by Lambin and Strahler (1994a, 1994b) from the multi-spectral vector concept (Malila, 1980; Vigar and Colwell, 1987) is used in the current study as a tool for comparing the two drought indices. The CVA has advantages in the consecutive data analysis and time-series data compression over other change detection methods (such as differencing or principal component analysis) since the two CVA variables, change magnitude and direction, can exclusively be calculated only by this technique. The CVA algorithm was coded onto a graphical modeling script within the ERDAS Imagine image-processing package (ERDAS, 1997).

To compare spatial distributions of the two drought indices, drought-occurred-area (DOA) map was created for every year, and compared to each other. The DOA for each index indicates occurrences and accumulations of droughts during the VGP for every year in relation to the reference year, 18-year median. The DOA of the two indices also was compared to drought-affected-area (DAA) map created from traditional ground-observed weather data. Although traditional method was used as validation for satellite data, the DAA only gives information if there was drought event in a certain year over a certain local level administration, named Soum. Therefore, although ground-observation data does not give

knowledge about aerial extension of drought or how larger areas were occurred by drought for certain Soum area, we considered that the whole territory of Soum was affected by drought.

Results and discussion

Temporal and spatial variations of NDVI and LST

Inter-annual variations of NDVI and LST for the three sub-periods of growing season during 18-year in the Desert-Steppe and Desert ecosystems are presented in Figure 2 (Appendix 5, Fig. 2). Along the study period, statistically significant differences of NDVI were exist between the three sub-periods in both the Desert-Steppe (F-stat=73.86, $p<0.0001$) and Desert (F-stat=9.89, $p=0.0002$) ecosystems. However, the NDVI is seasonally varied differently in two ecosystems. In the Desert-Steppe, the lowest NDVI values, about 0.07-0.1, were found at the early part of the VGP and higher values (about 0.12-0.19) were observed at the middle of the VGP (Appendix 5, Fig. 2a). The NDVI values in the late part of the VGP were located somewhere in-between them (about 0.1-0.16) but closer to the peak value in the season. Overall, the seasonal variation of the NDVI was high in the Desert-Steppe ecosystem than the Desert ecosystem. Contrary, less variation was found between the sub-periods of the season in the Desert ecosystems (Appendix 5, Fig. 2b). Also, the lowest values of the NDVI (0.04-0.07) were found at the middle of the VGP in the Desert ecosystem in contract to the early season in the Desert-steppe. Besides, the NDVI values in the Desert ecosystem throughout the 18-year period were low, varied from low (0.04-0.08) at the beginning of the growing season to high (0.06-0.1) at the end. The inter-annual variations of LST over the 18-year period shows that the peak of the LST were observed in the middle of the VGP (the hottest summer time) in both the Desert-Steppe (30-39°C) and Desert (35-45°C) ecosystems of Mongolia (Appendix 5, Fig. 2c and 2d). Clear separations between the sub-periods can be noticed (F-stat=178 for the Desert-Steppe and F-stat=218 for the Desert ecosystem). The lowest LST in both ecosystems were found at the beginning, while the highest at the middle of the VGP. These results suggest that the relations between the variations of NDVI and LST over the growing season can group the study years. The years 1984, 1988, 1990, 1993-94, and 1998, which are characterized by high NDVI and low LST, can be classified as wet years. Contrary, the years with low NDVI and high LST values, such as 1983, 1986, 1989, 1995-96, and 1999, as drought years.

The spatial distribution of the 18-year mean NDVI and LST values in sub-periods of the growing-season over the Desert-Steppe and Desert ecosystems is presented in Figure 3. (Appendix 6, Fig. 3) It can be seen that the NDVI and LST values are typically low at the beginning of growing season or springtime in two ecosystems (Appendix 6, Fig. 3a and 3d). The reason is the soil moisture is extremely low due to the low amount of rainfall during this time of the area. In addition, strong and enduring winds are common during springtime over the Desert-Steppe and Desert ecosystems when the air is warmed up (Natsagdorj, 2000). However, the higher NDVI values along with lower LST values were found in the northern part of the study area at this time of the season. The NDVI was high during the middle (i.e., summer) and end (i.e., autumn) of the VGP (Appendix 6, Fig. 3b and 3c) in the Desert-Steppe ecosystem in the northern and central parts of the study area, the Gobi-Altai Mountain and on the fringes of the Depression of Great Lakes, and forward to the south – Desert region. The LST was high in the middle of the season in the south and southwestern regions of the study area, the Gobi Desert, and the rising temperatures were spread to the north to the Desert-Steppe regions throughout the growing season (Appendix 6, Fig. 3e and 3f). Increase of LST at the beginning of VGP causes increase of NDVI values in the Desert-Steppe and vast areas of the Desert ecosystems. The NDVI variation during the middle of the VGP is not positively supported by the LST increases. Further, downward LST in the late of season aid to the NDVI when reach its peak at the end of the VGP. However, as an increasing of temperature at the beginning of the VGP in the south, plants might be affected by heat and/or water stress during the middle of the VGP (Appendix 6, Fig. 3b). Under such circumstances, plants cannot re-growth back later in the season, summer and autumn (Appendix 6, Fig. 3c). The decrease of the NDVI values at the middle and end of the VGP over some southern areas can be explained by increasing of temperature and evaporation over these areas. Hence, high temperature at the middle of the VGP does not support the growth of vegetation in the Desert ecosystem, however increasing temperatures aid to the plant growths in the Desert-Steppe.

Comparison of drought-detection indices derived from the NDVI and LST

Spatial distribution of drought occurred areas (DOA) detected by the two different drought indices derived from the NOAA-AVHRR reflective and thermal datasets over the VGP for three representative years, wet (1993 with 136 mm of annual precipitation), dry (1989 with 44 mm), and normal (1998 with 99 mm), in the Desert and Desert-Steppe ecosystems of Mongolia is shown in Figure 4. (Appendix 7, Fig. 4) Despite the comparison of two indices, those two were evaluated against the traditional drought-affected-area (DAA) maps, except for the normal year 1998 (no data available). It should be noted that the traditional method does not distinguish between sub-periods of the VGP, as can be done with the image derived indices.

Figures 4a and 4b (Appendix 7, Fig. 4) illustrate DOA maps or spatial distribution of droughts that are detected in different sub-periods of the VGP in 1993 (wet year) by the NDVI and LST/NDVI, respectively. Only some areas are detected by two drought-indices in this year. These are identified as droughts at the beginning of the VGP occurring in the same places in the northwest and northern parts of the study area on the DOA maps of NDVI (Appendix 7, Fig. 4a). However, these areas were not declared as droughts in DAA map by traditional observations (Appendix 7, Fig. 4c). In this year, relatively larger areas are identified as late (August-September) drought on the DOA maps of LST/NDVI (Appendix 7, Fig. 4b) while some of them are marked as drought events in the DAA map (Appendix 7, Fig. 4c). Small areas are identified as beginning and late droughts (e.g., April-May & August-September) by the DOA maps of LST/NDVI over the central and south-west parts of the study area (Appendix 7, Fig. 4b) whereas the DAA map marks larger areas as drought-affected (Appendix 7, Fig. 4c) and no droughts are detected by other the NDVI (Appendix 7, Fig. 4a).

In contrast to the wet year, when precipitation was significantly below normal in 1989, drought events affected large areas as shown by the DOA maps of NDVI (Appendix 7, Fig. 4d) and LST/NDVI (Appendix 7, Fig. 4e) as well as the DAA map (Appendix 7, Fig. 4f). Obviously, both indices detect much larger areas than in the wet year, as shown above. For the dry year, most drought events are identified by the NDVI as combinations of droughts in sub-periods of the VGP (rather than a single period) (Appendix 7, Fig. 4d). While, the LST/NDVI found several droughts in the middle, end, and entire duration of the VGP (Appendix 7, Fig. 4e). However, none of the DOA maps of satellite-derived indices matches the DAA map (Appendix 7, Fig. 4f). In the latter, much larger areas were defined as droughts.

A small area in the northwestern fringe and some eastern and central parts of the study area are identified as droughts at different sub-periods of the VGP in 1998 (normal year) by the DOA maps of NDVI (Appendix 7, Fig. 4g). However, relatively larger areas in the southern fringe of the study area are identified as drought during the middle and end of the VGP by the LST/NDVI (Appendix 7, Fig. 4h). Also, small areas are identified entirely as drought during the VGP on the DOA maps of LST/NDVI. Other than a few areas in the east of the study area, spatial distributions of DOA maps of the drought indices do not show similar results in sub-periods of VGP in the normal year.

Summary

Remote sensing indices derived from the reflective and thermal datasets of the NOAA-AVHRR sensor for 18-years from 1982 to 1999 were used to examine the temporal and spatial variations of the NDVI and LST in the Desert-Steppe and Desert ecosystems of Mongolia. Negatively varied NDVI and LST during the VGP in two ecosystems led to the suggestion that the drought events can be predictable more reliable by the combination of these two variables than the use of a single one. Comparison of DOA maps of the two indices shows that they do not show similar results for sub-periods of the VGP. Also, results indicate that there are no agreement in detecting of droughts between the satellite-derived drought-detection indices and the traditional ground-observed drought-affected-areas maps. Wider areas are detected as droughts by ground-observation rather than satellite derived drought-detection indices. Although this can be explained by the different observation methods (ground vs. remote sensing), it can be concluded that ground measurements are less precise over wide regions. This finding should be verified with respect to the indices based on meteorological parameters (e.g., temperature and precipitation).

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