Drought Monitoring Using the Modified Temperature/Vegetation Dryness Index

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***Abstract*—Based on the EVI/Ts feature space which was constructed by land surface temperature (Ts) and Enhanced Vegetation Index (EVI) extracted by MODIS data, the modified temperature/vegetation drought index (MTVDI) was calculated to monitor the drought status of Inner Mongolia Autonomous Region from 9 May to 11 July. The meteorological data and soil moisture data were collected to compare with MTVDI. The correlation analysis was carried out between MTVDI and the cumulative precipitation of the same period(cpsp), the early 16 days(cpe16), the early 30 days(cpe30) and the early 60 days(cpe60). The correlationship between MTVDI and the mean temperature was analyzed in the same way. It implied that the correlation between MTVDI and the cumulative precipitation of the same period became lower and lower, which demonstrated that rainfall has a lagging effect. It depended on the cumulative precipitation in the present period whether the correlation between MTVDI and the cumulative precipitation of the same period or of the previous was significant or no. There was no significant difference in the correlations between MTVDI and the mean temperature of the same period or the previous for two periods, which were from 9 May to 24 May and from 26 June to 11 July with light drought. In heavy drought periods from 25 May to 9 June and from 10 June to 25 June, the correlation coefficient between MTVDI and the mean temperature of the same period was much higher than the previous time, which proved that the drought status was aggravated by high temperature. Finally, the soil moisture data (0-10cm) measured by agro-meteorological stations was carried out linear correlation analysis with MTVDI. The result showed that MTVDI had a close relationship with surface soil moisture and it can be used as an indicator to monitor the drought status.**

Keywords- MODIS; EVI; Land surface temperature; TVDI

I. INTRODUCTION

The traditional methods, such as field survey, can not be used to monitor and assess the drought conditions at large scale. Nevertheless, remote sensing techniques have enjoyed many benefits in drought monitoring and early warming, due to their wide coverage, short return period, easy access and relative lower expense[1]. To monitor the drought by remote sensing has been focused on by the scientists in the world. The methods which are used to monitor the soil water status with the multispectral technique in visible and thermal infrared wavelength are listed below: thermal intertia measuring method, vegetation index measuring method, crop water shortage index measuring method(CWSI) and the methods of combining vegetation index and land surface temperature[2], et al.

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Since there are close relationships between land surface temperature(Ts) and vegetation index[3], we can obtain the drought indicator for different vegetation coverage conditions according to the spectral reflection characteristic and land surface temperature(Ts). Thus, muti-temporal remote sensing data can be used to monitor the drought status. Sandholt[4] developed the Temperature/Vegetation Dryness Index (TVDI) to estimate the surface soil water content of different vegetation coverage conditions. It was also applicated to estimate the dryness status of the south of Hebei province[5]. The method of TVDI is simple to use and has a definite physical meaning, so it has been used widely. But there are also some problems with this method resulted from the use of NDVI. NDVI is easy to be saturated, the correction for the atmospheric influence is not considered enough and the effect generated by soil background is not processed, and so on[6]. Thus,EVI has been used to replace NDVI to construct MTVDI to monitor the distribution and dynamics of dryness in the humid Guangxi province[7].

The study area includes Inner mongolia autonomous region, which is far away from ocean, located in the north border of China. The average annual precipitation is from 30mm-500mm. The precipitation variability is high. There are almost two out of every three years in which different levels of dryness occured. The dryness restrains the agriculture and pasture's development[8]. The Terra/MODIS products of land surface temperature(Ts) and vegetation index were applied to construct EVI/Ts space, and the MTVDI was used to study the drought status from May to July in 2007 in Inner mongolia autonomous region. The meteorological data and soil moisture data were collected to compare with MTVDI.

II. BASIC PRINCIPLES

The MTVDI takes EVI to replace NDVI to construct dryness index, which has the same principles with TVDI and can monitor the dryness status most effectively.

A. The principles of TVDI to monitor drought status

Price[9] and Carlson[10] et al. found that the remote sensed Ts and NDVI construct the triangular scatter diagram in the area with vegetation coverage condition from bare soil

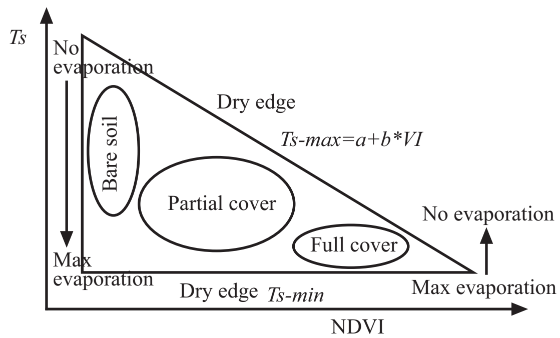

Figure 1. Simplified Ts/NDVI space(Sandholt et al.,2002)

to complete coverage and with soil moisture status from extreme arid to humid. Sandholt et al. developed the TVDI, and the formula of its calculation is expressed as

$$TVDI = (Ts - Ts_{\min})/(Ts_{\max} - Ts_{\min}) \quad (1)$$

Where Ts is the land surface temperature of every given pixel; $Ts_{max} = a_1 + b_1NDVI$ is the fitting equation of the dry edge, which is the observed maximum surface temperature corresponding to a given NDVI, whose theoretical soil water content should be "0"; $Ts_{min} = a_2 + b_2NDVI$ is the fitting equation of the wet edge,which is the observed minimum surface temperature corresponding to a given NDVI, whose theoretical soil water content should equal to field water capacity. The higher the TVDI value the lower the soil moisture content is(Fig. 1).

B. *Enhanced vegetation index(EVI)*

The effects on the red band generated by aerosol can be eliminated because the difference of aerosol scattering caused by blue and red band is considered in EVI. Therefore, many problems can be solved, for example, NDVI is easily to be saturated and the linear relationship between NDVI and actual vegetation coverage is not significant. EVI can really reflect the vegetation conditions, which can reduce the effect on vegetation information by soil background through adopting the principle of soil adjusted vegetation index[6]. So, EVI is used in this study, the calculation formula is expressed as follows:

$$EVI = 2.5(\rho_{NIR} - \rho_{RED})/(\rho_{NIR} + c_1\rho_{RED} - c_2\rho_{Blue} + L) \quad (2)$$

Where ρ is the reflecting value of each band (NIR, Red and Blue) after atmospheric calibration. NIR, Red and Blue band corresponds to the 2nd, 1st and 10th band of MODIS 1B data respectively; L=1: soil adjusted factor; c_1 and c_2 equals to 6.0 and 7.5 respectively.

III. DATA PROCESSING

A. *Remote sensing data*

Two kinds of MODIS data downloaded from the NASA website were used in this study: the 8-day composite land surface temperature (Ts) MOD11A2 product with a 1 km spatial resolution and the 16-day composite ground vegetation index (the enhanced vegetation index, EVI) MOD13A2 data with the same spatial resolution, which were acquired during the periods from 9 May to 11 July in 2007. Both kinds of images were geometrically rectified to the UTM projection system using a polynomial model available through MRT, one coordinate conversion software for MODIS products. The land surface temperature data were made to 16-day composite data with the average value of two 8-day ones so that it can correspond to the EVI data.

B. *Meteorological data*

The daily mean temperature and precipitation data were collected by 49 meteorological stations from March to September in 2007 in the study area. The mean temperature and cumulative precipitaion were calculated for four periods of 9 May to 24 May, 25 May to 9 June, 10 June to 25 June, 26 June to 11 July and each period's early 16 days, early 30 days, early 60 days. Meanwhile, the soil moisture data of every ten days for 19 agro-meteorological stations were also collected from May to July.

IV. MTVDI MODEL APPLICATION

The EVI-Ts scatter chart was constructed by pixel value of the EVI and land surface temperature (Ts) of the study area. Land surface temperature of the pixels which have the same EVI value was extracted, then the lowest surface temperature (Ts_{min})was extracted further. EVI and the corresponding Ts_{min} were carried out linear regression to get the wet edge fitting equation. The dry edge fitting equation can be obtained through the same way (Fig. 2). Based on this, the temperature of each pixel in both dry edge and wet edge were calculated, and the MTVDI can be obtained according to (1). According to the classification standard of TVDI used in other research[11], the drought status was divided into five grades: wet (0-0.2), normal (0.2-0.4), light drought (0.4-0.6), moderate drought (0.6-0.8), heavy drought (0.8-1.0). As can be seen from Fig. 3, the heavy drought areas were distributed mostly in the west and southwest of Inner Mongolia autonomous region in the middle and late stage of May in 2007. From the end of May to early June, heavy drought areas shrinked significantly in the west; however, the heavy drought areas expanded in the mid-east. According to the precipitation data of 49 meteorological stations in the study area, most areas of Inner Mongolia lack rainfall in the mid-advanced June, so that the central region was in moderate drought status and drought-stricken areas expanded obviously in the eastern and western. In early July, the drought status in most parts of Inner Mongolia relieved a lot because several rainfall events had occurred, and most area of Inner Mongolia autonomous region changed from heavy drought to moderate drought. There were still some heavy drought areas in the eastern and western regions.

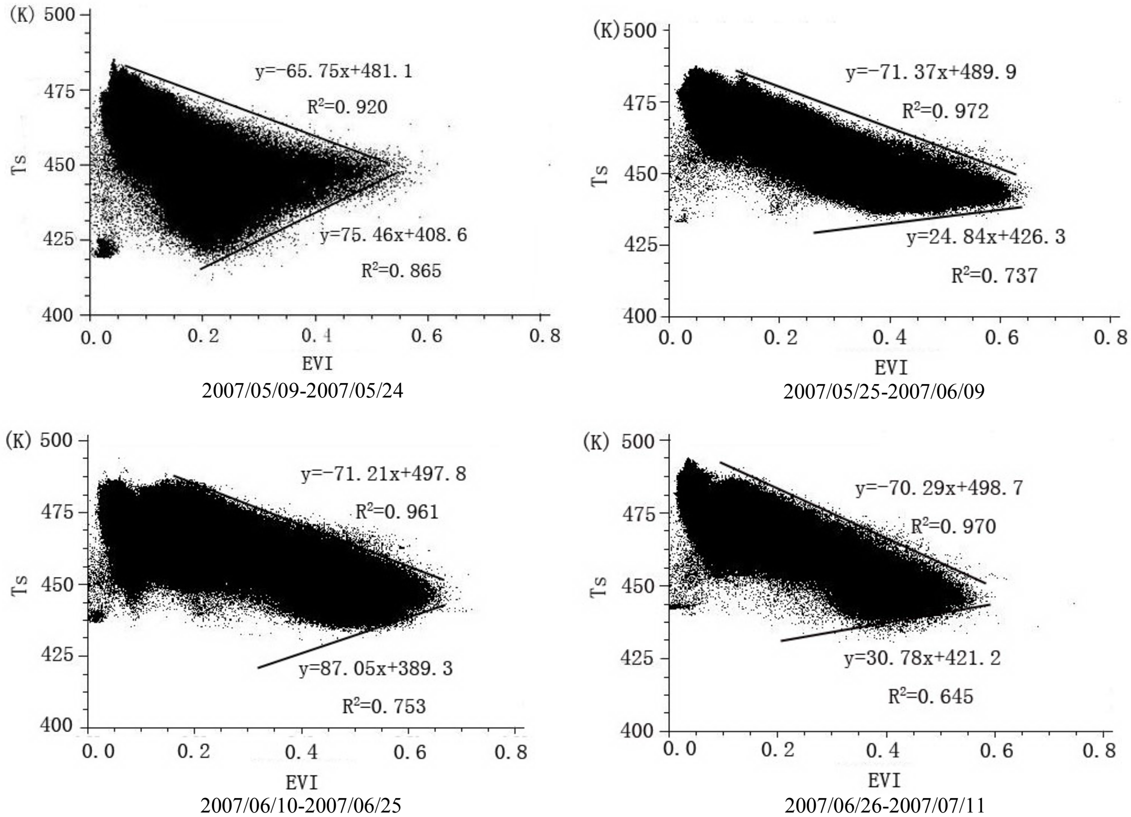

Figure 2. Scatter plot of both dry edge and wet edge in EVI-Ts space at every time interval

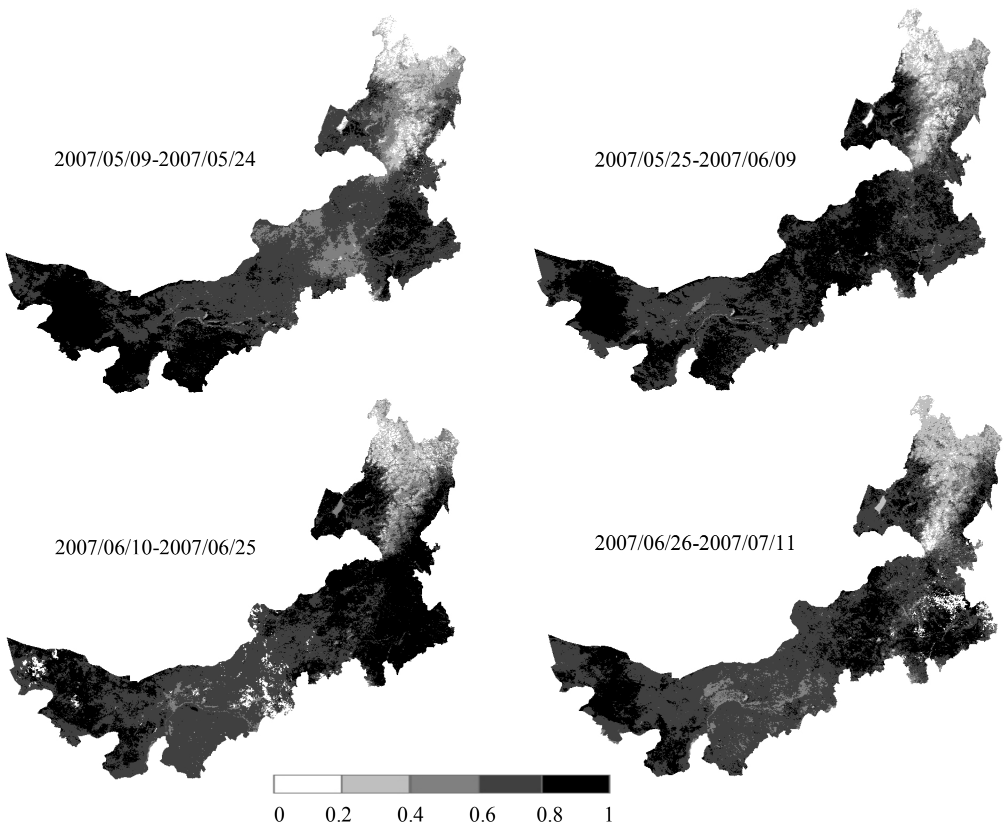

Figure 3. The MTVDI distribution of the study area from June to July in 2007

Table 1． The linear correlation coefficient between MTVDI and the cumulative precipitation

	Cpsp	Cpe16	Cpe30	Cpe60
9 May -24 May	0.55**	0.39	0.17**	0.20
25 May -9 June	0.43*	0.51**	0.53**	0. 60**
10 June –25 June	0.33*	0.10	0.20	0.30
26 June –11 July	0.11	0.14	0.18	0.33*

Significance level of correlation coefficient：**,P<0.01;*,P<0.05.

Abbreviations:cpsp,the cumulative precipitation of the same period;cpe16,the cumulative precipitation of the early 16 days;cpe30, the cumulative precipitation of the early 30 days;cpe60, the cumulative precipitation of the early 60 days.

V. EVALUATION OF MTVDI

A. Response of MTVDI to rainfall

The cumulative precipitation was calculated in the ways as described in the section B of III. MTVDI and the cumulative precipitation which corresponded to the 49 meteorological stations in study area were carried out correlation analysis. The results were showed as Tab. 1.

According to Tab. 1, the correlation between MTVDI and the cumulative precipitation decreased from 9 May to 25 June. During the period of 26 June to 11 July, the correlation between MTVDI and the cumulative precipitating of the same period is not significant, which proved that the local rainfall events relieved the drought and made a lagging effect. Rainfall occurs mainly from June to August in Inner Mongolia, and the soil water is supplied by the rainfall and snow for the last year. As the soil moisture in sowing consumed, rainfall becomes the main way to relieve the drought and supply soil water in May. Therefore, MTVDI and the cumulative precipitation of the same period had a higher correlation coefficient in 9 May to 24 May. In the period of 25 May to 9 June, the correlation between MTVDI and cumulative precipitation of the same period was lower than that of the early 16 days, the early 30 days and the early 60 days for fewer rainfall events. During the period of 10 June to 25 June, the precipitation increased in most areas in Inner Mongolia, which made the correlation between MTVDI and the cumulative precipitation of the same period significant. Precipitation decreased once again and the drought status relieved a lot from 26 June to 11 July, which led to MTVDI only significantly correlated with the cumulative precipitation of the early 60 days. It showed that MTVDI is also able to reflect the drought caused by the lack of precipitation in the previous period.

Table 2. The linear correlation coefficient between MTVDI and the average temperature

	Mtsp	Mte16	Mte30	Mte60
9 May -24 May	0.71**	0.73**	0.71**	0.70**
25 May -9 June	0.61**	0.38	0.37**	0.37*
10 June –25 June	0.72**	0.31*	0.32*	0.29*
26 June -11 July	0.59**	0.55**	0.66**	0.57**

Significance level of correlation coefficient：**,P<0.01;*,P<0.05.

Abbreviations: mtsp,the mean temperature of the same period;mte16, the early 16 days mean temperature;mte30, the early 30 days mean temperature;mte60, the early 60 days mean temperature.

Table 3. The correlation between MTVDI and measured soil moisture

	R^2	P
9 May –24 May	0.351*	0.096
25 May -9 June	0.267*	0.014
June 10 -25 June	0.26*	0.026
June 26 -11 July	0.815**	0

Significance level of correlation coefficient：**,P<0.01;*,P<0.05.

B. Response of MTVDI to temperature

As it can be seen from Tab. 2, in the two periods of from 9 May to 24 May and from 26 June to 11 July, there was no significant difference in the correlation coefficients between MTVDI and the mean temperature of the same period, the early 16 days, the early 30 days and the early 60 days. It proved that temperature made larger effects and its lagging effect was obvious in a light drought status. In the periods of from 25 May to 9 June and from 10 June to 25 June, the correlation coefficients between MTVDI and the mean temperature of the same period was much higher than the previous time, which proved that the temperature lagging effect was not obvious in the heavy drought period. Continuous high temperature in these two periods would speed up the surface soil water evaporation (or transpiration), which would lead to a severe drought status because land surface water lacked more and more.

C. The relationship between MTVDI and soil moisture

The soil moisture data (0-10cm) which was measured by agro-meteorological stations from May to July in 2007 was carried out linear correlation analysis with the corresponding MTVDI of the same location (Tab. 3). It can be found that MTVDI had a good correlation with surface soil moisture. The correlation coefficients were all above 0.3 and located between 0.5-0.9. So, it is reasonable to dynamically monitor the drought status by using MTVDI which is calculated from EVI/Ts feature space.

VI. CONCLUSION

In this paper, based on the understanding of EVI/Ts feature space which was constructed by land surface temperature (Ts) and Enhanced Vegetation Index (EVI), the two data products of MODIS were used to generate MTVDI, which was used to monitor the drought status of Inner Mongolia Autonomous Region from 9 May to 11 July. The obtained conclusions were as follows:

- In the middle stage of May in 2007, heavy drought areas were mainly in the west and southwest of Inner Mongolia autonomous region. From the end of May to early June, the western heavy drought area shrinked significantly, but in the mid-eastern region heavy drought areas expanded. Lacking of rainfall led to the central region moderate drought in the mid-advanced June, while the eastern and western drought areas expanded a lot. Most parts of Inner Mongolia autonomous region changed from heavy drought to moderate drought in early July. But there were still some heavy drought areas in the eastern and western regions.

- Cumulative precipitation and mean temperature data were used to compare with MTVDI. It can be found that the correlation between MTVDI and the cumulative precipitation become lower and lower due to the lagging effect of rainfall from the late May to early July. It depended on the cumulative precipitation in the present period whether the correlation between MTVDI and the cumulative precipitation of the same period or of the previous was significant or not. There was no significant difference in the correlation coefficients between MTVDI and the mean temperature of the same period, the early 16 days, the early 30 days and the early 60 days in the light drought periods. But MTVDI correlated more significantly with the mean temperature of the same period than the previous time.
- There was a good correlation between MTVDI and the soil moisture(0-10cm) of the study area, which can further prove that MTVDI can be used as an indicator of the soil moisture to monitor drought status.

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