Study on the Influence and Correction of Spatial Heterogeneity of Air Temperature in Drought Remote Sensing Monitoring

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Abstract. Temperature Vegetation Dryness Index (TVDI) is one of the commonly used methods in remote sensing drought monitoring. Since this method requires the study area to be large enough to achieve the ideal fitting of the dry and wet edges of the temperature-vegetation feature space, the spatial heterogeneity of meteorological elements has a significant influence on the results. Taking Hebei Plain as an example, the air temperature data at the moment of satellite transit are used to modify the surface temperature retrieved by remote sensing, that is, the surface temperature subtracts the spatial heterogeneity of air temperature, to eliminate the influence of the spatial heterogeneity of air temperature on the TVDI index. TVDI index and surface temperature before and after correction are compared in this paper. The results show that the spatial heterogeneity of air temperature does have a significant effect on TVDI index, and the surface temperature distribution after temperature correction is more reasonable, and will not have great effect on the method of using TVDI to monitor the degree of drought. It can be seen that the correction of surface temperature is more helpful to improve the accuracy of agricultural drought monitoring.

1. Foreword

Drought, considered as a common and serious natural disaster, has an inescapable impact on agricultural production, afflicting 45% of the world’s land and causing hundreds of billions of dollars in economic losses every year [1-3]. China is a large agricultural country and has always attached great importance to the research and application of agricultural drought monitoring methods [4]. Traditional agricultural drought monitoring uses artificial or instrumental observation at ground stations to obtain precipitation, air temperature, soil moisture and other information. Due to limited density of the stations, it is difficult to understand the temporal process and spatial characteristics of the occurrence of drought [5]. Traditional agricultural drought monitoring costs a great deal of manpower, material resources and financial resources, and the information obtained by this way is still limited in scope and the information is of poor timeliness. As a new technology, remote sensing technology makes up for the deficiency of traditional agricultural drought monitoring. Remote sensing technology has the characteristics of wide detection range, fast data collection, large amount of required information and is objective. It can effectively monitor agricultural drought in large area [6-9]. Remote sensing drought monitoring includes...
visible light-near infrared remote sensing monitoring method, thermal infrared monitoring method and visible near-infrared - thermal infrared remote sensing monitoring method [10]. The commonly used indexes in the visible light - thermal infrared remote sensing monitoring method are Vegetation Health Index (VHI), Vegetation Supply Water Index (VSWI) and Temperature Vegetation Dryness Index (TVDI) [11-13]. Among which, the TVDI index is a method for retrieving soil moisture in vegetation coverage areas based on optical and thermal infrared remote sensing data [14], which has been widely used.

The application of the TVDI index requires that there be a range from extreme humidity to extreme drought for any vegetation condition in the monitoring area, therefore, the study area should be large enough to meet the application condition of this method [15]. Large study area brings many influencing factors for monitoring, among which the spatial heterogeneity of air temperature is the most important problem should be solved. From the point of view of surface energy balance, the influencing factors of surface temperature are not only the distribution of latent heat flux and sensible heat flux, but also the air temperature, that is, the surface temperature is affected by evaporation and spatial temperature, thus, it is necessary to correct the spatial heterogeneity of air temperature. In order to eliminate the effect of spatial heterogeneity of air temperature on agricultural drought monitoring results, some scholars have provided solutions. Wu Zhijie et al. replaced NDVI with NDMVI and used mountain vegetation index to extract vegetation information to eliminate the impact of topography [16]. On this basis, Zheng Famei et al. introduced DEM data to correct the impact of topographic relief on TVDI, that is, to solve the influence of surface temperature changes with topographic change, thus improving the accuracy of drought monitoring [17-18].

Based on the principle of surface energy balance, this study considers the influence of the spatial heterogeneity of air temperature on the TVDI index in large-area remote sensing drought monitoring by using TVDI. The air temperature data at the time of satellite transit is introduced, and the spatial heterogeneity of air temperature is used to eliminate its impact on surface temperature, thereby improving the accuracy of remote sensing monitoring of drought in large area.

2. Data and Methods

2.1 Research area

The research area is located in the Hebei Plain in the south of Hebei Province, namely the plain area of Beijing-Tianjin-Hebei (see Figure 1). Hebei Plain is the area north of the Yellow River in the North China Plain. It is formed by the alluvium of the Yellow River and Haihe River. The elevation is below 100 meters and the terrain is not very undulating. This research area is plain, which can avoid the impact of topographic relief on surface temperature and reduce the error caused by topographic factors in the calculation of TVDI index. The study area is located in the mid-latitude area and belongs to temperate monsoon climate with four distinct seasons and abundant sunshine. In terms of precipitation, the precipitation is more in the southeast and less in the northwest. Although the precipitation is not sufficient, the concentrated precipitation in summer, which is regarded as the growing season, accounts for 50%-75% of the whole year. This research area is China's main grain production area. The main crops are corn, wheat, vegetables, cotton and so on. This region contains 4 latitudes from north to south and about 3 longitudes from east to west. The monitoring range is large enough to meet the application premise of the TVDI method, but it is susceptible to other factors. Therefore, the study of agricultural drought monitoring in this area is of great value in production and application.
2.2 Data sources
MODIS is an important sensor aboard the TERRA and AQUA satellites. It has 36 spectral wavelengths of medium resolution (0.25um ~ 1um) and views the Earth's surface once every 1-2 days [20]. Based on the thermal infrared band of MODIS, the surface temperature can be retrieved by the split-window algorithm, so it is widely used in the field of agricultural monitoring. This research uses the daily products of MODIS remote sensing data on October 30, 2019, including daily surface reflectivity products MOD09GQ and surface temperature product MOD11A1. The air temperature data at the time of the satellite transit comes from the Hebei Meteorological Bureau. There were 85 meteorological stations evenly distributed in the study area (see Figure 1).

2.3 TVDI calculation method
In this study, we used the Temperature Vegetation Dryness Index (TVDI) for drought monitoring, which was first proposed by Sandholt et al. and is now widely used in drought monitoring [21]. TVDI is closely related to Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST). NDVI is also known as the change of biomass index, and its formula is as follows:

\[ NDVI = \frac{NIR - RED}{NIR + RED} \]  

where, RED and NIR are the surface reflectivity of red and near-infrared bands, respectively.

The scatter plot constructed by NDVI and LST in the monitoring area is usually triangular, and the upper and lower boundaries of the space are extreme dry edge and wet edge, respectively. Using these 2 boundaries, the TVDI index of any point can be calculated by interpolation. As can be seen from Figure (2), the wet edge (Ts_MIN) and the dry edge (Ts_MAX) are the lowest and highest surface temperatures corresponding to any NDVI in the monitored area.

Figure 1 Study area and distribution of meteorological stations
Figure 2 Surface temperature-vegetation index characteristic space diagram of the method TVDI.

The fitting equations of wet edge and dry edge are as follows:

\[ T_{S\_MIN} = a_1 + b_1 \times NDVI \]

\[ T_{S\_MAX} = a_2 + b_2 \times NDVI \]  \hspace{1cm} (2)

where, \( T_{S\_MIN} \) is the minimum surface temperature corresponding to the same vegetation index value, i.e. the wet edge temperature; \( T_{S\_MAX} \) is the maximum surface temperature corresponding to the same vegetation index value, i.e. the dry edge temperature; \( a_1, b_1 \) are the coefficient of the wet edge fitting equation in the characteristic space; \( a_2, b_2 \) are the coefficient of the dry edge fitting equation in the characteristic space. For any point in the feature space, the TVDI can be calculated using its NDVI and \( T_s \):

\[ TVDI = \frac{T_s - (a_1 + b_1 \times NDVI)}{(a_2 + b_2 \times NDVI) - (a_1 + b_1 \times NDVI)} \]  \hspace{1cm} (3)

where, \( T_s \) is the surface temperature at any point, and its corresponding vegetation index is NDVI. The TVDI value of wet edge is 0 and that of dry edge is 1. Combined with the actual ground features, the closer the TVDI value is to 0, the more humid the soil is, and vice versa. The closer the TVDI value is to 1, the more arid the soil is.
3. Results and Analysis

3.1 Comparison before and after TVDI correction

As can be seen from Figure 3a and 3b, with the change from high latitude to low latitude, the TVDI value increases gradually in the range of 0 to 1, that is, there is a clear transitional difference in soil moisture between the north and the south, and the soil moisture in the south is higher than that in the north, and there is a gradual change phenomenon. The transition of soil moisture in Figure 3a is obviously different from the actual situation. In actual production, influenced by precipitation and irrigation, the soil moisture in farmland should be distributed randomly or patchily. As it can be seen from Figure 3b, with the change from high to low latitudes (from north to south), the corrected TVDI value changes irregularly from 0 to 1, i.e., there is no obvious gradual change in soil moisture between north and south. The random differences in the figure may be caused by other factors such as local precipitation and regional characteristics. In Figure 3a, the original MODIS surface temperature product $T_s$ is used in the calculation of TVDI. Figure 3b is the TVDI result after temperature correction, and the surface temperature data is corrected using the method of $T_s - (T_p - \bar{T})$, in which $T_p$ and $\bar{T}$ are the spatial air temperature interpolation and the average air temperature of 85 meteorological stations respectively. The corrected TVDI index redistribution is more random and more consistent with actual situation.
3.2 Influence of spatial heterogeneity of air temperature on surface temperature

As shown in Figure 4a, there is an obvious gradient distribution of surface temperature. As the latitude changes from north to south, the surface temperature shows a gradually increasing trend, that is, the surface temperature between north and south is obviously different, the temperature of south is obviously higher than that of north, and there is a clear trend of gradual change. In Figure 4b, the surface temperature corrected by the spatial heterogeneity of air temperature no longer shows the characteristic of gradual change from north to south, that is, there is no significant difference in surface temperature between north and south, and the surface temperature exhibits a random distribution, which is more in line with the actual situation.

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Figure 4 Comparison of surface temperature before and after correction (unit: K) (a is before the correction, b is after the correction).

Figure 5 Variation of air temperature with latitude at time of satellite transit.

From the surface energy balance, we can know that the solar net radiation is mainly used for the surface temperature rise and transpiration, the higher the soil moisture content, the larger the surface transpiration, and the lower the surface temperature. In addition, air temperature is the most direct factor affecting the surface temperature. Figure 5 shows the variation of the temperature with latitude at the time of satellite transit in this study. It can be seen that the air temperature has obvious spatial gradual changes with latitude and gradually decreases with the increase of latitude. Combined with the spatial distribution of surface temperature before and after correction in Figures 4a and 4b, it can be seen that
the air temperature has significant effect on surface temperature. Therefore, it is necessary to carry out surface temperature correction. This method, which uses the spatial heterogeneity of air temperature to correct the surface temperature, effectively improves the accuracy of the TVDI value, and can truly reflect the difference in the surface energy balance caused by the difference in soil moisture content.

3.3 The influence of temperature spatial heterogeneity on TVDI characteristic space

![Figure 6 Fitting dry and wet edges in the characteristic space of the surface temperature and vegetation index before and after correction (a is before the correction, b is after the correction).](image)

Compared with Figure 6a and 6b, there is no significant change in the shape of the land surface temperature-vegetation index characteristic space before and after the correction, which indicated that the surface temperature after excluding the influence of temperature differences will not have a significant impact on the method of TVDI to monitor the degree of surface drought. After the surface temperature correction, the intercept of the wet edge fitting equation changed from 286.93 to 287.29, and the slope changed slightly from 1.57 before the correction to 1.1957 after the correction. It can also be seen from the figure6 that the fitting equation of the dry edge does not change very much, which shows that the surface temperature, after excluding the influence of the spatial heterogeneity of the air temperature, only makes a small correction to the characteristic space, which is corrected by the calibration of the dry edge and the wet edge in the characteristic space, so as to improve the remote sensing retrieval accuracy of TVDI index.

4. Conclusion and discussion

In view of the influence and correction of spatial heterogeneity of air temperature, which is a problem faced by TVDI method requiring the study area to be large enough to obtain the ideal fitting of the dry edge and wet edge of the surface temperature-vegetation index characteristic space, this paper puts forward a method to correct the TVDI value by modifying the surface temperature with the meteorological data. By using the air temperature interpolation ($T_p$) of satellite transit time to minus the mean value of air temperature data ($T_\theta$), the spatial heterogeneity data of air temperature distribution can be obtained, i.e. $T_p - T_\theta$, and then using the difference between surface temperature ($T_s$) and this value ($T_s - (T_p - T_\theta)$), the influence difference of air temperature on surface temperature is eliminated and the correction of surface temperature can be realized, and the modified surface temperature is used to retrieve the TVDI index. The results show that this method can improve the remote sensing retrieval accuracy of TVDI and increase the accuracy of agricultural drought monitoring.

In this paper, the surface temperature is corrected by meteorological data, and the accuracy of agricultural drought monitoring is improved to some extent, but there is still some uncertainty. This study remains at the theoretical level, and the remote sensing retrieval accuracy of TVDI is not verified on the ground measurements, which should be improved in future studies, and the practical application of remote sensing in agricultural drought monitoring should be considered.
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