THE CALCULATION OF TVDI BASED ON THE COMPOSITE TIME OF PIXEL AND DROUGHT ANALYSIS

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ABSTRACT:

Temperature-Vegetation Dryness Index (TVDI) is one of the agriculture drought indexes. This paper presents a data composite method which improves the calculation of TVDI through taking the time of pixel into consideration, and the adaptability of TVDI in drought assessment has also enhanced significantly. First, the Normalized Difference Vegetation Index (NDVI) data series are composed by using maximum value composite (MVC) method, and the Land Surface Temperature (LST) data series are composed to construct NDVI-Ts feature space. Then, the wet and dry sides of NDVI-Ts feature space are fixed by a number of ways to build new TVDI, and we note it as T-TVDI, for assessing the drought condition. To verify our proposed method, TVDI in time scale of ten-days is established for Chongqing region in China, and the results coincide with the actual situation. Finally, the T-TVDI and TVDI of Chongqing region in 2008 are calculated and compared. The correlations of them and Soil Moisture are analyzed as well as Precipitation. It shows that T-TVDI has the advantages of stability and high accuracy in the short term. It is feasible to use T-TVDI to evaluate drought in proper region and reasonable crop growth period.

1. INTRODUCTION

The water stress indicator (TVDI) proposed from NDVI-Ts feature space reflecting the surface soil moisture well, especially in large areas of vegetation coverage, is used to assess the drought condition locally.

In the NDVI-Ts feature space, the expression of TVDI calculation is as follows:

$$\mathrm{TVDI} = \frac{T_s - T_{s-\min}}{\mathrm{T}_{\text{s-max}} - T_{s-\min}} \tag{1}$$

Where $T_{s-\min}$ = minimum of land surface temperature When the NDVI is equal to a particular value
$T_{s-\max}$ = maximum of land surface temperature When the NDVI is equal to a particular value

We can see from the above equation (1), NDVI and LST data are the bases for the TVDI calculation. The NDVI is calculated from near-infrared and red bands of the multispectral image, and the LST data is able to get by split-window algorithm. Drought is a complex phenomenon, the formation and development of its strength go through a process in gradual accumulation which is so slow that it is difficult to detect during beginning period. In the process of TVDI calculation, NDVI and LST data are composed by time-series data accumulated in a certain observing period. The rationality of composite algorithm is directly related to the quality and accuracy of TVDI.

There are a number of conventional composite methods of NDVI and LST, such as MVC, CV-MVC and BRDF (These methods will be gave explanatory notes in what follows). Whichever method is used, composites of NDVI and LST data are carried out separately. Although TVDI is the statistical values of the period, there are no real spatial and temporal consistency of geography and time between the vegetation condition and surface temperature which reduces the calculation accuracy and evaluation effects of drought. This paper analyzes the principles and characteristics of TVDI firstly, and then composes the NDVI and LST based on the time of pixel; finally carry out T-TVDI with a good evaluation of drought in the region.

2. THE CALCULATION OF T-TVDI

2.1 Introduction to the theory of TVDI

Temperature Vegetation Drought Index uses the relationship between the surface temperature and soil moisture (relative soil moisture) to reflect degree of drought.

TVDI comprehensively considers relation and changes between the NDVI and LST. From the physical mechanism, it is certainly hysteretic to using NDVI as Water Stress Index. Temperature is time-sensitive as indicator of water stress, but is apt to be affected by vegetation coverage when using temperature method to monitor soil moisture. TVDI integrates vegetation indices and surface temperature to monitor soil moisture with the ability to composite information of visible, near infrared and thermal infrared bands of light, so it has a wider range of applicability. Figure 1 shows the simple NDVI-Ts feature space.

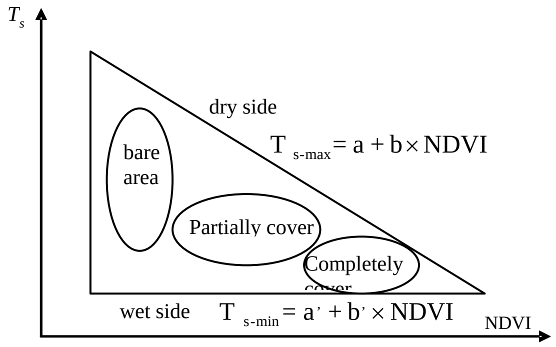

Figure 1. Simple NDVI-Ts feature space

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The NDVI-Ts feature space is able to be simplified to a triangle,

$T^{s-\max}$ and $T^{s-\min}$ are linearly fit at the same time, and result is as follow:

$$T_{s\text{-max}} = a + b \times NDVI$$
$$T_{s\text{-min}} = a' + b' \times NDVI \quad (2)$$

$$TVDI = \frac{[T_s - (a' + b' \times NDVI)]}{[(a + b \times NDVI) - (a' + b' \times NDVI)]} \quad (3)$$

where a, b, a', b' = coefficients of dry side and wet side fitting equation

The range of TVDI is [0, 1], TVDI = 1 on the dry side, TVDI = 0 on the wet side. The greater the value of TVDI, the lower the soil moisture, and the higher the level of drought will be.

2.2 The composite of NDVI and LST

The purpose of composite is to choose the best observational data. This method should be able to ensure spatial and temporal consistency of vegetation index values. At present, there are following common ways of composite:

MVC(*maximum value composite***):** Select the maximum NDVI value of observed pixel as the vegetation value in composite period. It is the best method for information with no atmospheric correction because of minimizing the selection of cloudy and heavy aerosol pixels.

CV-MVC(*constraint view angle maximum value composite***):** The CV-MVC compares the two highest NDVI values and selects the observation closest to nadir view to represent the 16-day composite cycle. This helps to reduce spatial and temporal discontinuities in the composite product.

BRDF(*bidirectional reflectance distribution function***):** The BRDF scheme is a more elaborate and constrained technique in which all bidirectional reflectance observations, of acceptable quality, are utilized to interpolate to their nadir-equivalent band reflectance values from which the VI is computed and produced.

Because composites of NDVI and LST data are carried out separately by the methods above, although TVDI is the statistical values of the period, there are no real spatial and temporal consistency of geography and time between the vegetation condition and surface temperature which reduces the calculation accuracy and evaluation effects of drought.

In this paper, MVC and CV-MVC method are applied in accordance with the following priority sequence of composite methods:

1. CV-MVC within limited perspective: If in the period of composition, the number of days with no cloud is less than 30%, and more than 2, choose the maximum of two vegetation indexes within smallest perspective.
2. Calculating the vegetation index directly: If there is only one day without cloud, choose the vegetation index of the day directly.
3. MVC: If all days observed is not sunny, choose the maximum of al the vegetation index values in the composite period.

While composing the NDVI, the time information obtained of every composite pixel in ten-days are stored in a band. Then choose the corresponding pixel to compose LST from LST data series referring to the time raster chart.
The specific algorithm is stated as follows:

```
For x = 0 to Xsize
  For y=0 to Ysize
    For i = 0 to dayCount
    If the count radio of sunny day is under 30%:
      If the count of sunny equal one
        NDVComposite[x,y] = NDVI[i]
        Day[i] = the date of NDVI[i]
      Else
        NDVComposite[x,y] get the maxNDVI
        day[i] = the date of maxNDVI
      Endif
    Else
      NDVComposite[x,y] = maxNDVI of two values within smallest perspective
      day[i] = the date of maxNDVI
   Endif
   EndFor
   dateComposite[x,y] = day[i]×100
   LSTComposite[x,y] = LST[i] of day[i]
  EndFor
```

EndFor
EndFor

NDVComposite[x,y], dateComposite[x,y] and LSTComposite[x,y] are separately composite data of NDVI, date image and LST. Day[i], LST[i] and NDVI[i] respect separately pixels of date image, LST and NDVI series in ten-days. The figure 2 shows the visualization of this method.

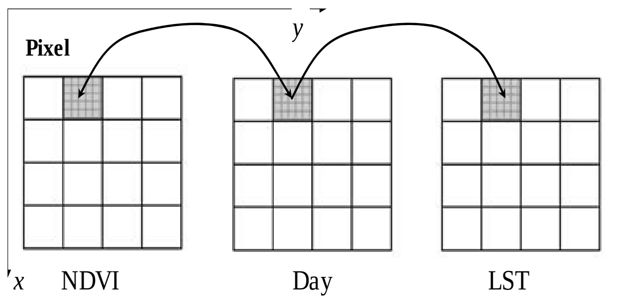

Figure 2. Composite of LST referring to the time raster chart

2.3 Fixing of wet and dry sides

The maximum and minimum temperature corresponding to NDVI as the thermal and cold edges of NDVI-Ts feature space are obtained by method of maximum and minimum. The thermal and cold edges obtained by the method are direct-viewing, clear and easy-to-linear fitting with rapidly handling and showing. But sometimes the pixels of the sides are scattering and shapes are irregular. Then we will consider using the scatter plot to fix the thermal and cold edges.

Fix the wet side referring to the average of cold edge (base on the cloud removing), water surface temperature and average in the same period of many years in the region. According to the histogram of image, remove the pixels at the end of the thermal edge with fixing the boundaries at 1% of the total number of pixels, and obtain the parameters of dry side by linear fit. Due to irregular thermal edge, the parameters may be not good. Then, we set up a standard feature space as background reference picture according to the relationship between wet and dry sides. It can be used to adjust and fix the parameters of wet and dry sides. Standard feature space previously divides the LST in appropriate interval in feature space, and then establishes the equations of all corresponding dry sides. This method remains an error. But with the smaller the intervals, the error is smaller. The parameters of dry side are replaced by corresponding contour in reference picture of standard feature space as following figure.

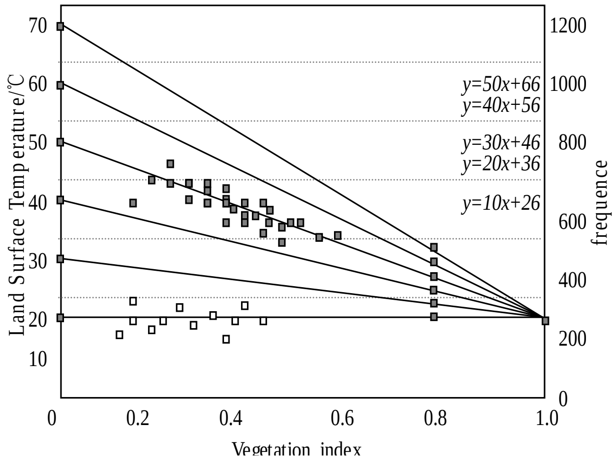

Figure 3. Picture of standard NDVI-Ts feature space

3. EXPERIMENT OF T-TVDI CALCULATION

In this paper, Chongqing region in China is selected as the experimental area where the typical southern dry farming areas are with frequently occurrence of drought.

The data using in the paper include remote sensing data and measured data. Remote sensing data with 1-km resolution is provided by MODIS (Moderate Resolution Imaging Spectroradiometer), and measured data (soil moisture and rainfall) in the experiment are from all the hydrological stations located in various parts of Chongqing region (Figure 8 & Figure 9). Soil moisture data are from calculation of measured data in the depth of 10cm, 20cm, and 50cm of soil.

First of all, calculate the LST through split-window algorithm using NDVI dataset. Then, two methods of TVDI calculation are adopted. One is the method using MVC to compose NDVI and LST series of 10 day. The other is the methods composing NDVI and LST data by the way mentioned above, extracting the minimum and maximum LST in different climatic zones and every ten-days under the different conditions of NDVI with a small step size.

The NDVI-Ts feature spaces from two methods are as follow (data of ten days are acquired in mid-May 2008):

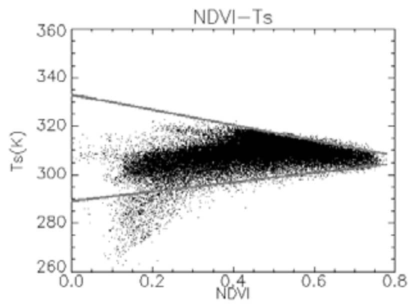

Figure 4. NDVI-Ts feature space based on the Composite Time of pixel

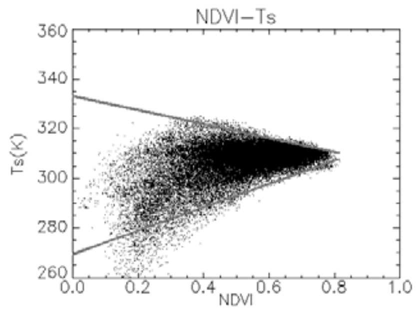

Figure 5. NDVI-Ts feature space based on MVC

As can be seen from the figures above, angle of triangle in the second feature space is bigger than the first one, because most of LST concentrate in high-temperature region, especially in the wet side. It is difficult to fix the boundaries of LST. Slope of dry side is less than 0, indicating that LST is decreasing with the vegetation coverage increase. On the contrary, the slope of wet side is greater than 0, indicating that there is increasing trend for LST while vegetation coverage decreases.

According to scatter gram of the first feature space, fit the wet and dry sides as follows:

$$\begin{aligned} T_{s\text{-}max} &= 5.6 + 34.5 \times NDVI \\ T_{s\text{-}min} &= 13.5 - 40.5 \times NDVI \end{aligned} \qquad (4)$$

Finally the T-TVDI result from calculation shows that heavy-dry appeared in the middle, southeast and small part of east of Chongqing region. RSM(*relative soil moisture*) of northern areas is suitable for the growth of crops, and light-dry appeared in south-western regions. From the experimental results, detection is generally consistent with the reality.

The figure 6 shows the result of T-TVDI calculation:

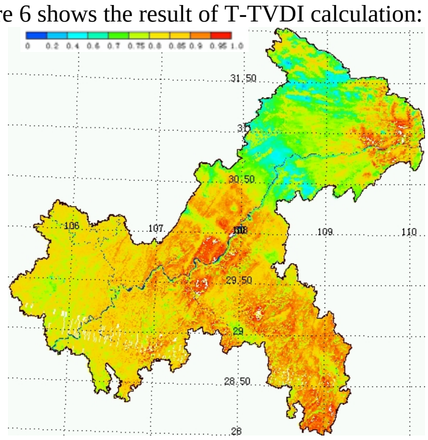

Figure 6. T-TVDI of Chongqing in mid-May 2008

4. DROUGHT ANALYSIS

Soil moisture and rainfall are two normal indexes to evaluate soil drought situation, they can better reflect the intensity and duration of drought situation. Soil moisture is the field soil moisture and the corresponding crop water status, as one of the indicators of drought situation. It plays an important role in the exchange between the water and energy exchange of surface and atmospheric. Relative Soil Moisture can be offset the impact of soil texture to some extent. Figure 7 shows the relative soil moisture and stations of Chongqing in mid-May 2008. As can be seen, spatial distribution of relative soil moisture is uneven that in the north is less than in the south.

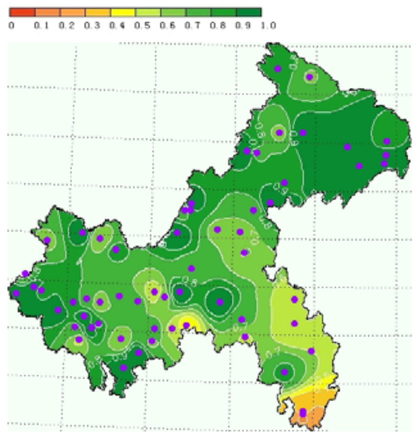

Figure 7. Relative soil moisture and stations of Chongqing in mid-May 2008

Precipitation is the main factors affecting drought situation, the amount of precipitation reflects the weather conditions basically. Standard Precipitation Index (SPI) is easy to compute and access to necessary information, and because of not involving a specific mechanism of drought situation, the space-time adaptability is more suitable. The figure 8 shows standard precipitation index and stations of Chongqing in mid-May 2008. The graph shows that the rainfall in most parts of the province ten days is less than normal. The west of Chongqing seriously lack of rainfall.

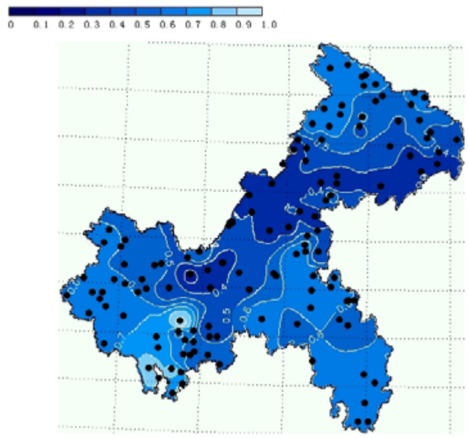

Figure 8. Standard precipitation index and stations of Chongqing in mid-May 2008

The scatter plot of T-TVDI and RSM from Chongqing in mid-May 2008 is given in the following, as well as the scatter plot of T-TVDI and RSM.

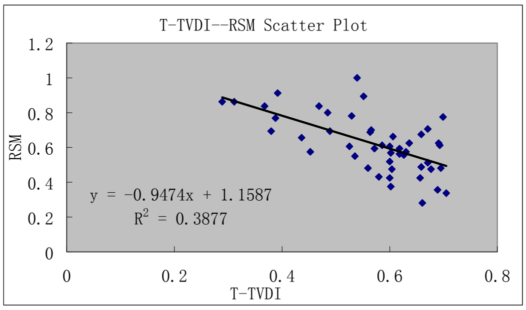

Figure 9. Scatter plot of T-TVDI and RSM in mid-May 2008 of Chongqing

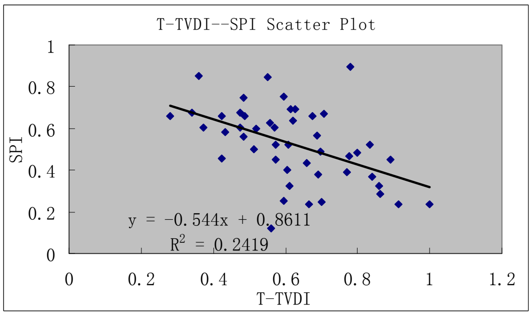

Figure 10. Scatter plot of T-TVDI and SPI in mid-May 2008 of Chongqing

As can be seen from figure 9 and figure 10, it is obvious that scattered points distribute nearby on both sides of a straight line and show a good linear distribution that indicating a good linear model. The correlation arrives 0.62 and the linear model has passed the significance level F test with reliability of 0.01. At the same time, T-TVDI also has a good correlation with SPI, indicating T-TVDI has a good effect in evaluating the situation of the regional drought.

To carry out further analysis and evaluation of drought situation, this paper uses two kinds of TVDI data calculating from MODIS data covering Chongqing region in every ten-days to analyze the adaptive real-time indices. The analysis of adaptive real-time indices is respect that doing correlation analysis between the index and RSM in the ten-days. It emphasizes adaptability of index at the time to RSM, and provides a basis for choosing real-time index for drought monitoring. As a reference, two types of indexes and the precipitation index are analyzed in the same way.

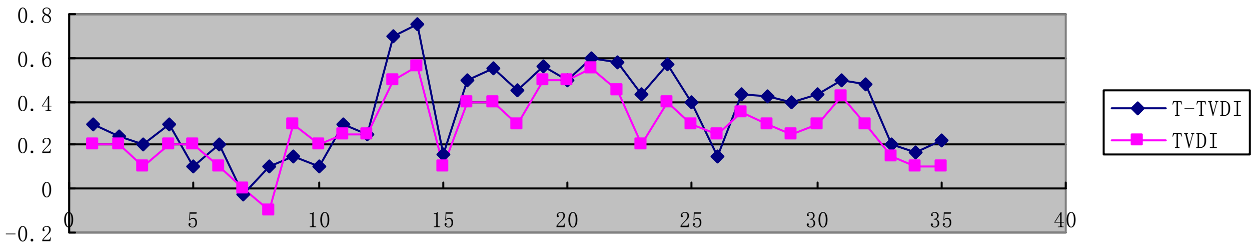

Figure 11. Correlations gram between RSM and two indexes of Chongqing in 2008

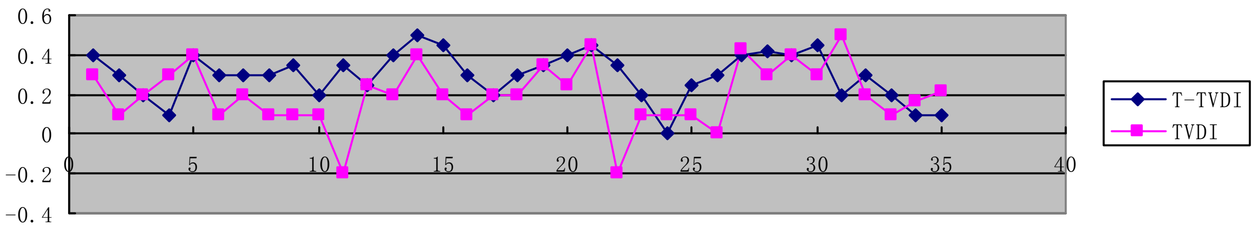

Figure 12. Correlations gram between SPI and two indexes of Chongqing in 2008

The figure 11 shows that in the winter the two indexes are not too high correlating with RSM, this is because of the low vegetation cover in winter, the TVDI sensitivity is not high for the ground. In the crop growing period, the correlation is increasing with the crop growing,. The correlation of T-TVDI and RSM is better than TVDI.

The figure 12 shows that T-TVDI and TVDI are not good correlating with SPI, but the trend of T-TVDI was relatively stable, so it is an acceptable range of fluctuation for the evaluation of drought situation.

5. CONCLUSION

This paper uses two different composite methods to obtain NDVI and Ts in ten-day scales from MODIS data in 2008, and then constructs the NDVI-Ts feature space. On the basis of this NDVI-Ts feature space, TVDI and T-TDVI that reflecting the drought situation are created and used to evaluate the drought situation. Comparing with the surface soil moisture data and precipitation data getting from hydrological observation sites , the result shows that , TVDI basing on the composite time of pixel can better reflects the correlation with soil moisture, more suitable for monitoring and evaluating drought situation.

TVDI only adapts to a relatively high vegetation coverage area, the higher of vegetation coverage, and the greater of the correlation with the RSM. Because of the significant difference of wet and dry side in different regions, the evaluated range should not be too big by using TVDI.

Because satellite view affects the amount of information received by sensors, thus vegetation growth status shows in images further. This study does not take into account the impact of satellite view to the NDVI and LST.

6. ACKNOWLEDGEMENT

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