

## STUDY ON SOIL MOISTURE BY THERMAL INFRARED DATA

by

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*Information on soil moisture is important for environment management. This study bases on the daily observation to study the normalized difference vegetation index and to classify the index data. The results indicate that: (1) the index is able to adequately reflect the changes of soil moisture content in 10 cm and 20 cm thickness of soil layer during the vegetation growth period and (2) Information on soil moisture can be used for regional drought monitoring. The method can be extended for long-term monitoring of droughts over large-scale regions.*

*Key words: thermal inertia, land surface temperature, temperature vegetation dryness index, drought, soil moisture*

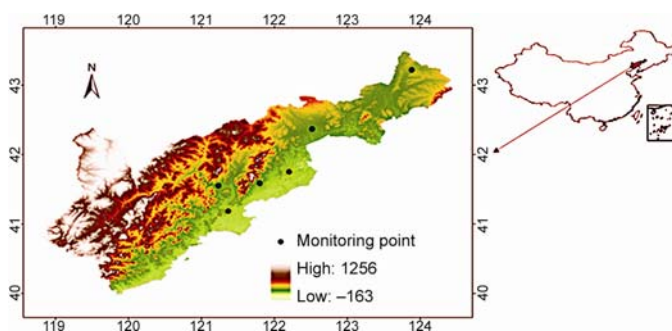
### Introduction

Drought is a complex natural phenomenon, which is caused by a regional imbalance in water supply and demand [1]. The traditional monitor drought method using meteorological data is not timely and accurate. Optical satellite sensors complemented with thermal infrared channels have received much attention as a source of information on soil moisture content and surface evaporation [2]. Several satellite-based indices have been developed and used to effectively detect and monitor droughts. The normalized difference vegetation index (NDVI) [3] and the thermal inertia index has been the most widely used for evaluating drought conditions. In addition, the potential of using remote sensing data obtaining information about the energy and water status of a surface has been investigated by several authors [4-7]. All these studies indicate that NDVI provides little information about soil water content and land surface temperature (LST) which is relatively related to water stress, the combination of LST and NDVI can provide better information on vegetation and moisture conditions at the surface. A simplified method, the temperature vegetation dryness index (TVDI) based on an NDVI-LST combination, has been suggested for assessment of surface moisture status. In this study, MODIS NDVI and LST data (MOD11A2 and MOD13A2 data) are used to construct TVDI model to investigate drought monitoring in northwest of Liaoning Province.

### Study area

Located in northeast China, between latitude 39.9-43.6 and longitude 118.8-124.7 (fig. 1), the study area covers approximately 68,000 km<sup>2</sup>. Precipitation in Liaoning as a whole diminishes consistently from southeast to northwest. Average annual precipitation in study area is about 500 mm, three-fourths of it falling between June and September and almost none from December through February. The rainfall resource is limited in amount and uneven in

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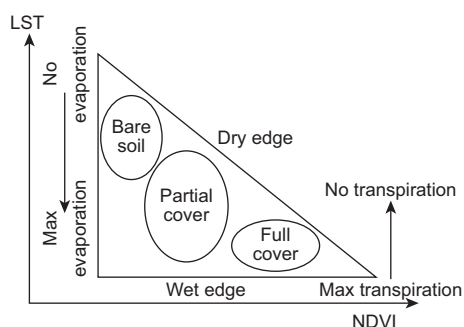
**Figure 1.** The location of the study area in northwest of Liaoning Province, China

(for color image see journal web site)

area, Terra/MODIS data is selected as main data source. The EOS/MODIS imagery has moderate spatial resolution, high temporal resolution, and high spectral resolution. In addition, it is free and easy to access. In this paper, MODIS/terra land surface temperature/emissivity 8-day L3 global 1 km SIN grid V005 (MOD11A2) dataset are used to acquire land surface temperature, MODIS/terra vegetation indices 16-day L3 global 1 km SIN grid V005 (MOD13A2) dataset are used to acquire NDVI. Data time series from April 2000 to September 2000 and May 2012. MOD11A2 and MOD13A2 are both downloaded from EOS data gateway (<http://reverb.echo.nasa.gov/reverb>) using the web-based search.

#### Data pre-processing

The MOD11A2 and MOD13A2 images downloaded covers a large extent of north-east China, which should be extract the study area before starting calculation. The MODIS land products are distributed by USGS in hierarchical data format (HDF) and projected into sinusoidal (SIN) projection. Neither the storing format nor the projection is well supported in conventional data-processing software [2]. Thus, for the convenient further usage, each scene is re-projected to a more commonly used projection as Universal Transverse Mercator (UTM, WGS84). The ERDAS9.2 software is used to carry out aforementioned pre-processing.



**Figure 2.** The relationship between LST/NDVI [11]

ing to plant water deficit, leaf temperature rises relative to air temperature. The higher soil background temperature would severely interfere with this information if only temperature is

seasonal distribution, causing frequent droughts in this place. Northwest region is a primary bread basket in Liaoning Province, winter wheat, maize and cotton are the main crops and the coverage rate of vegetation is relatively high.

#### Data and methodology

##### Data acquisition

In order to monitor soil moisture variation of study area, Terra/MODIS data is selected as main data source. The EOS/MODIS imagery has moderate spatial resolution, high temporal resolution, and high spectral resolution. In addition, it is free and easy to access. In this paper, MODIS/terra land surface temperature/emissivity 8-day L3 global 1 km SIN grid V005 (MOD11A2) dataset are used to acquire land surface temperature, MODIS/terra vegetation indices 16-day L3 global 1 km SIN grid V005 (MOD13A2) dataset are used to acquire NDVI. Data time series from April 2000 to September 2000 and May 2012. MOD11A2 and MOD13A2 are both downloaded from EOS data gateway (<http://reverb.echo.nasa.gov/reverb>) using the web-based search.

##### Methodology

TVDI method based on MOD11A2 and MOD13A2 data is used to evaluate drought status in study area. A simplified representation of the concept of the TVDI is presented in fig. 2. The TVDI is related to soil moisture, where the NDVI is strongly correlated with the amount of vegetation, but it is often referred to as a greenness index rather than a moisture index. The LST reflects the state of soil moisture, but which is more sensitive to water stress due to the relationship between leaf temperature and transpiration [6, 8, 9]. As the transpiration rate is reduced owing to plant water deficit, leaf temperature rises relative to air temperature. The higher soil background temperature would severely interfere with this information if only temperature is

considered when the ground is not covered completely by vegetation. Thus, The linear combination of NDVI/LST normally shows a strong negative relationship and could form a triangle shape if the study area is large enough to provide a wide range of NDVI and LST conditions [10, 11].

LST is the observed surface temperature and NDVI is the observed normalized difference vegetation index at the given pixel.  $LST_{min}$  is the minimum surface temperature in the triangle defining the wet edge and  $LST_{max}$  is the maximum surface temperature defining the dry edge. The dry edge and wet edge calculated from the NDVI-LST space regression with small intervals of NDVI ( $LST_{max} = a1 + b1 \cdot NDVI$ ,  $LST_{min} = a2 + b2 \cdot NDVI$ ), and  $a1$ ,  $b1$ ,  $a2$ ,  $b2$  are parameters defining the dry edge and wet edge modeled as a linear fit to data.

## Results and discussion

### NDVI-LST space

According to TVDI model building method, a spatial calculation model is designed with ERDAS9.2 software, which can extract the maximum and minimum LST corresponding to NDVI. The NDVI-LST scatterplots for the 2000 dry seasons (fig. 3) show that the pixels in each DOY scatterplot clearly form a triangle, indicating a wide range of surface soil moisture in study areas. These observations are consistent with the TVDI concept that NDVI increases with a decrease of LST.

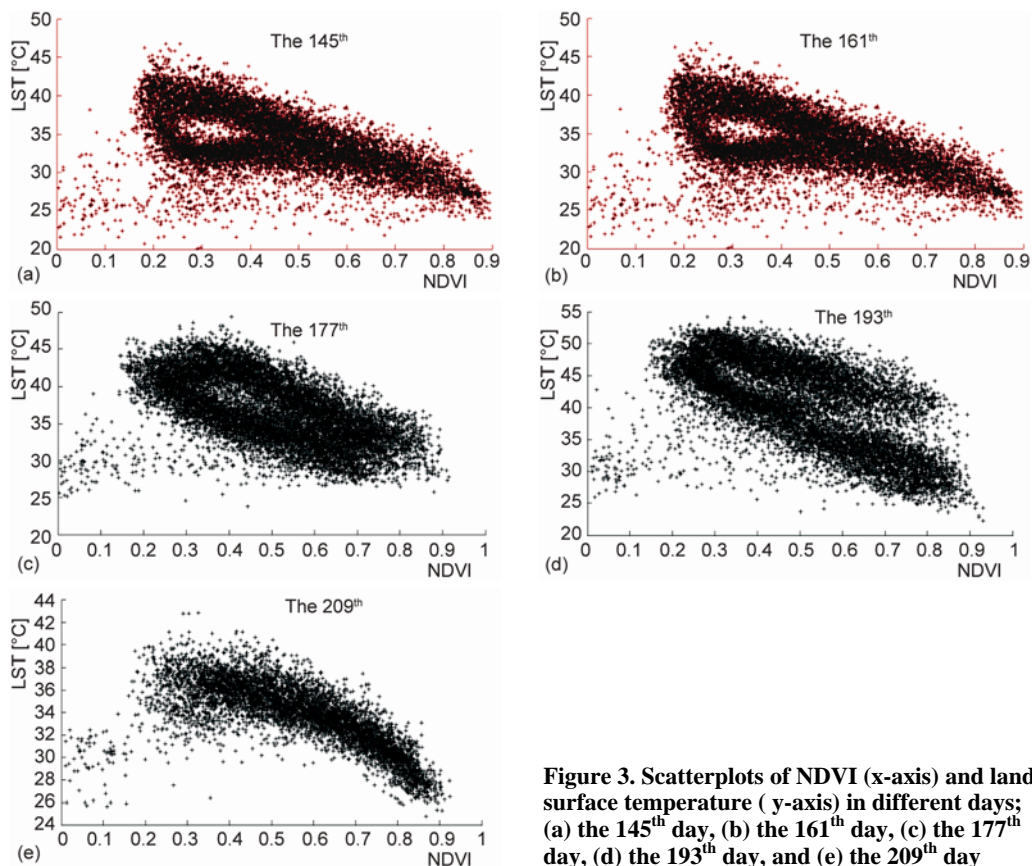


Figure 3. Scatterplots of NDVI (x-axis) and land surface temperature (y-axis) in different days; (a) the 145<sup>th</sup> day, (b) the 161<sup>th</sup> day, (c) the 177<sup>th</sup> day, (d) the 193<sup>th</sup> day, and (e) the 209<sup>th</sup> day

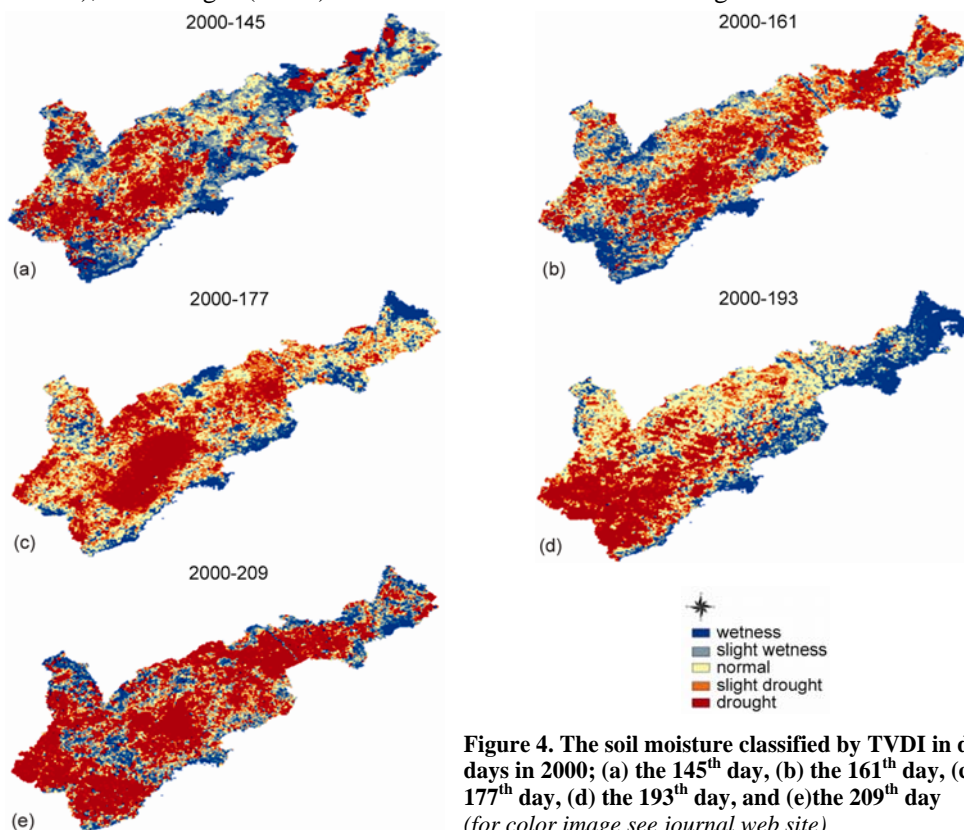
**Table 1.** The dry and wet edges in LST/NDVI space estimated by linear regression for every 16 days from May to August in 2000

DOY	Dry edge	Wet edge
145	$LST = -18.8817 NDVI + 44.6482$	$LST = -8.3354 NDVI + 35.6507$
161	$LST = -22.5748 NDVI + 50.1436$	$LST = -12.2925 NDVI + 40.6637$
177	$LST = -18.5444 NDVI + 48.3541$	$LST = -14.9916 NDVI + 41.8492$
193	$LST = -27.1277 NDVI + 57.3733$	$LST = -23.8596 NDVI + 50.3577$
209	$LST = -15.0778 NDVI + 41.2203$	$LST = -13.7894 NDVI + 38.4885$

0 at the wet edge, indicate maximum evaporation from the soil or unlimited moisture supply. In order to determine the parameters describing the dry edge and wet edge, the  $LST_{max}$  and  $LST_{min}$  observed for small intervals of NDVI is extracted in the LST/NDVI space (fig. 3). The parameters are found using least squares linear regression on the sloping side of the upper edge and under edge (tab. 1).

#### Describe drought conditions

The higher TVDI value shows that the lower soil moisture. We used ArcGIS software to calculate TVDI of each images. The TVDI is categorized into five classes describing drought conditions: wetness (0-0.2), slight wetness (0.2-0.4), normal (0.4-0.6), slight drought (0.6-0.8), and drought (0.8-1). The classification results are in fig. 4.



**Figure 4.** The soil moisture classified by TVDI in different days in 2000; (a) the 145<sup>th</sup> day, (b) the 161<sup>th</sup> day, (c) the 177<sup>th</sup> day, (d) the 193<sup>th</sup> day, and (e) the 209<sup>th</sup> day (for color image see journal web site)

#### Calculate dry edge and wet edge

The TVDI values range from 0 to 1, when TVDI = 1 at the dry edge, indicate no evaporation from the soil or limited moisture supply; and TVDI =

*Relationship between the observed soil moisture and TVDI*

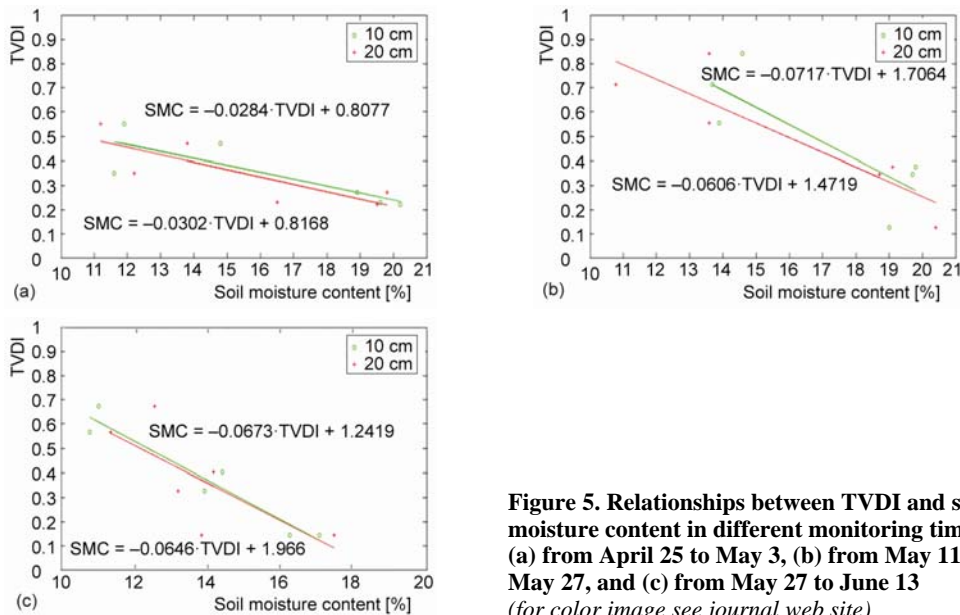
As soil moisture database in northwest of Liaoning Province is not complete, data collected during the April 2000 to July 2000 field survey is used to study relationships with the TVDI and soil moisture. The location of six monitoring point is shown in fig. 1, and the corresponding observed values of TVDI and soil moisture are shown in tab. 2.

**Table 2. TVDI corresponds to the soil moisture content of monitoring point**

Monitoring point soil thickness		Monitoring period					
		SMC	TVDI	SMC	TVDI	SMC	TVDI
Wang-Baoqing	10 cm	18.9	0.27	20	0.37	15.4	0.16
	20 cm	19.8	0.27	19.3	0.37	16.9	0.16
Yi xian	10 cm	11.9	0.55	13.9	0.71	8.6	0.60
	20 cm	11.2	0.55	11	0.71	9.3	0.60
Zhangwu	10 cm	11.6	0.35	14.1	0.45	8.9	0.71
	20 cm	12.2	0.35	13.8	0.45	10.8	0.71
Linghai	10 cm	20.2	0.32	19.2	0.12	16.4	0.16
	20 cm	19.5	0.32	20.6	0.12	12.4	0.16
Hujia	10 cm	14.8	0.47	14.6	0.84	13.1	0.43
	20 cm	13.8	0.47	13.2	0.84	12.8	0.43
Bajiazi	10 cm	19.6	0.23	19.9	0.34	12.5	0.35
	20 cm	16.5	0.23	18.9	0.34	11.6	0.35

SMC: soil moisture content [%]

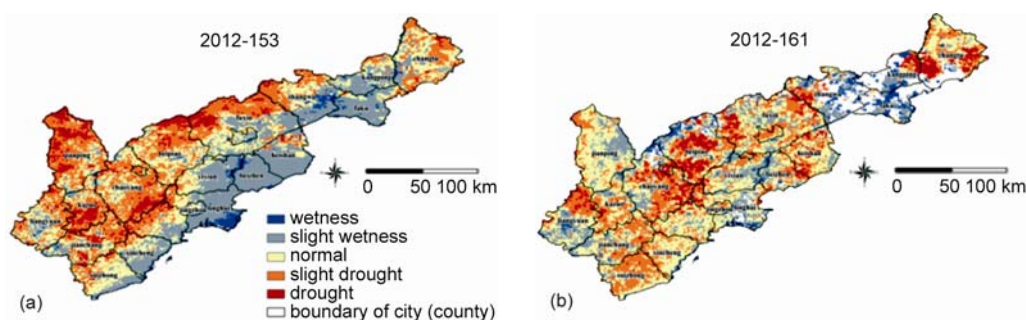
The relationship between soil moisture and TVDI is found to be negative as shown in fig. 5. Furthermore, the figure shows that there is a significant relationship between them at the depth of 10 cm and 20 cm.



**Figure 5. Relationships between TVDI and soil moisture content in different monitoring time; (a) from April 25 to May 3, (b) from May 11 to May 27, and (c) from May 27 to June 13 (for color image see journal web site)**

### Drought monitoring in May 2012

The verified TVDI model is used to implement drought monitoring. Drought conditions in May 2012 are shown in fig. 6. It can be seen from the thematic maps that the drought grade of northwest of Liaoning Province is mainly slight drought in May 2012. From May 1 to May 17, the ratio of drought area to study area is 10%. In May 1, the drought regions mainly contain Jianping, Beipiao, Kazuo, Fuxing, and Chaoyang, the normal regions mainly contain suizhong, liangyuan, and the wetness regions mainly contain Linghai and Beizhen. In May 17, the drought regions mainly contain Beipiao, Chaoyang and Changtu, the normal regions mainly contain Suizhong, Liangyuan, Kazuo, Yixian, and Jianping, and the wetness regions mainly contain Zhangwu and Faku. As a whole, the drought conditions show an decreases trend in study area. Comparing the TVDI values and land cover classification map found that bare soil and tilled fields always have higher TVDI values in comparison with mountainous rangeland and shrubs in the study area. In addition, the normal and slight wetness conditions monitoring by TVDI are more corresponds with the realities of the situation.



**Figure 6.** The soil moisture monitoring based on TVDI in 2012; (a) the 153<sup>th</sup> day, and (b) the 161<sup>th</sup> day (for color image see journal web site)

### Conclusions

The TVDI model is constructed and verified, after which the classification grades based on the TVDI method in northwest of Liaoning Province are obtained and its spatial and temporal variation features are analyzed. The 16 days MODIS NDVI and thermal infrared data for drought monitoring are explored in northwest of Liaoning Province. The findings showed that TVDI was able to adequately reflect the changes of soil moisture content in 10 cm and 20 cm thickness of soil layer during the vegetation growth period. TVDI was more suitable for monitoring normal and wetness conditions. Information on soil moisture obtained from this study could be important for water resource management and irrigation scheduling for crop production. Our findings demonstrated the merit of using MOD13A2 and MOD11A2 data for regional drought monitoring, and the thermal infrared data were the ideal data source for soil moisture monitoring. The TVDI method can be extended to other places for long-term monitoring of droughts over large-scale regions.

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