REMOTE SENSING RETRIEVAL OF SOIL MOISTURE IN GUANGXI BASED ON ATI AND TVDI MODELS

Xianjian Lu^{1,*}, Bin Zhou¹, Hongbo Yan¹, Le Luo¹, Yuhui Huang¹, Chenglong Wu¹ ¹College of Geomatics and Geoinformation, Guilin University of Technology, Guilin 541004, China-2008056@glut.edu.cn

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ABSTRACT:

In order to further to improve the monitoring accuracy of soil moisture spatial and temporal changes in Guangxi, this paper uses MODIS, Landsat8, ASTER GDEM data and measured relative soil moisture data as data sources. According to the design idea of complementary advantages, the EVI value of Landsat8 image is partitioned, and the relative soil moisture is inverted by ATI model method in the area of EVI \leq 0.33, and the relative soil moisture is inverted by TVDI model in the area of EVI>0.33. The apparent thermal inertia model (ATI) and the temperature vegetation drought index model (TVDI) was used to invert the relative soil moisture in Guangxi. The results show that the temporal variation of relative soil moisture in the study area in 2017 is the change cycle from rising to falling: the rising period is from January to July, and the falling period is from August to December, in which the relative soil moisture reaches the peak in July. The minimum value are December; the relative soil moisture in the north of Guangxi are generally higher than that in southern Guangxi. The correlation between the relative soil moisture value of the ATI model and the TVDI model partition retrieval and the measured relative soil moisture data is higher, and the relative soil moisture retrieval effects is better.

1. INTRODUCTION

Soil moisture is one of the main parameters in the fields of climate, hydrology, ecology and agriculture. It plays an important role in the exchange of matter and energy at the interface between the surface and the atmosphere. Surface soil moisture is also an important factor affecting soil wind erosion(Wang Y S., 2012). The study of the source of natural dust is of great significance, and soil moisture plays an important role in crop growth. The natural resources and geological environment in Guangxi are complex and diverse, with obvious regional differences, including 50 karst counties (cities). The natural environment in the karst area are extremely fragile, the surface water seepage is serious, the groundwater is buried deep, and the dynamic range is large, leading to serious natural disasters such as drought(Xiao P F., 2017). Therefore, it is of great significance to accurately grasp the content and variation in soil moisture for formulating reasonable measures to prevent and combat drought. The relative soil moisture retrieval based on remote sensing technology is one of the main ways of soil moisture monitoring in the region today. At present, in the remote sensing monitoring of regional relative soil moisture, many scholars have established a number of relative soil moisture retrieval models, which are based on apparent thermal inertia (ATI)(Liu Z H et al .,2006; Ding Z H,. 2014; Ma C F et al., 2012) and temperature vegetation drought index (TVDI)(Gao P X et al .,2018; Gao Y P et al.,2017; Guo R N et al.,2018) .The retrieval model is a model that has been widely used and has high precision in recent years. However, the retrieval carried out by a single model ignores the application scope of the retrieval model. For example, the apparent thermal inertia model is only suitable for bare soil and low vegetation coverage area, while the temperature vegetation drought index model is only suitable for medium and high vegetation coverage area(Yan H B et al., 2017).

At present, the remote sensing retrieval research of relative soil moisture in Guangxi by using the above models is mainly focused on drought assessment in spring and autumn (Li J L et al.,2014). However, the remote sensing retrieval research of annual relative soil moisture and the complementary application of the two models is still rare. n this paper, the Guangxi area is used as the research area. In view of the advantages and disadvantages of retrieval of relative soil moisture in the model of apparent thermal inertia model and temperature vegetation drought index model, two models are combined to conduct annual bimonthly retrieval studies to realize the complementary advantages of the two models. Construct a relative soil moisture remote sensing retrieval models suitable for the application of this study area to achieve comprehensive monitoring and evaluation of relative soil moisture in the study area.

2. STUDY AREA AND RESEARCH DATA

2.1 Overview of the Study Area

Guangxi Zhuang Autonomous Region (referred to as Gui) is located in the southwest of China's coastal areas. The Tropic of Cancer runs through the central part of the country. It belongs to the mid-subtropical, southern subtropical and northern tropical regions from north to south. It is affected by the East Asian monsoon and has a monsoon climate. Located at the southeast edge of yunnan-guizhou plateau, the terrain slopes from northwest to southeast, with continuous mountains, complex topography, interlaced mountains and valleys, and staggered rivers, thus forming the unique valley landform characteristics of Guangxi basin "notch". Guangxi has a total land area of 236,700 square kilometers, with a lot of mountains and little land. Low mountains, hills and stone mountains account for 70.8% of the total area of Guangxi. In 2008, the total cultivated land area of Guangxi was 4.431 million hectares, accounting for 19.1% of the total land area. Geographical coordinates of the land of Guangxi: 104°29 'E west, 112°04' E winter solstice, 20°54 'N south (Xian yang island), 26°20' N north, tropic of cancer passes through Wuzhou, Shanglin and Napo line. The geographical location is shown in figure 1.

^{*} Corresponding author



2.2 Research Data Sources

2.2.1 Remote Sensing Data

This article uses three data onto the Terra satellite MODIS standard products of January to December 2017: 1) MOD11A2 (time resolution for 8 ds, spatial resolution of 1 km) land surface temperature products, including day and night land

surface temperature data; 2) MOD13A2 (time resolution of 16 d, spatial

resolution of 1 km) rasterized vegetation index synthesis products, including 16-day synthetic enhanced vegetation index and normalized vegetation index data; 3) MOD09A1 (time resolution) Standardized surface reflectance data for 8 d, spatial resolution of 500 m), including reflectance values of the 1-7 from the US Geological Survey band. (USGS) (http://glovis.usgs.gov/).In the Guangxi region, the data set has 2 scenes per period, and the ranks are h27v06 and h28v06. And the image of the TM8 Guangxi area downloaded in July 2017 at the Earth Observation Center; the digital elevation DEM (with a spatial resolution of 30 meters) downloaded from the Science Center of the Chinese Academy of Sciences, resampling to 1 km by ENVI5.1.

2.2.2 Measured Relative Soil Moisture Data

The measured relative soil moisture data in this paper is 10 cm soil depth RSM observation data from 22 meteorological observatories in Guangxi from January 1 to December 31, 2017 (data monitored on the 26th of each month represents monthly data). Agricultural meteorological dataset from the Meteorological Data Center of China Meteorological Administration (http://data.cma.cn/). The distribution of weather station sites is shown in Figure 1, and the location information about each site is shown in Table 1.

Serial number	Site label	Site name	North latitude / °C	East longitude / °C	Serial number	Site label	Site name	North latitude / °C	East longitude / °C
1	59453	Yulin	22.65	110.16	12	59023	Hechi	24.7	108.05
2	59446	Lingshan	22.41	109.3	13	59001	Longlin	24.73	105.35
3	59426	Fusui	22.55	107.9	14	59211	Baise	23.9	106.6
4	59266	Cangwu	23.41	111.25	15	59431	Nanning	22.63	108.22
5	59249	Guigang	23.11	109.61	16	59632	Qinzhou	21.95	108.62
6	59228	Pingguo	23.31	107.58	17	59640	Hepu	21.67	109.18
7	59227	Tian deng	23.08	107.15	18	59254	Guiping	23.4	110.08
8	59218	Jingxi	23.13	106.41	19	59058	Mengshan	24.2	110.52
9	59044	Shatang	24.4	109.3	20	57957	Guilin	25.33	110.3
10	59037	Duan	23.93	108.1	21	57955	Xingan	25.63	110.65
11	59034	Yizhou	24.5	108.83	22	57947	Rongan	25.21	109.4

Table 1. Weather Station of Guangxi

3. PRINCIPLES AND METHODS

3.1 ATI And TVDI Principle

3.1.1 Apparent Thermal Inertia

Soil thermal inertia is a thermal property of soil. It is an intrinsic factor that causes the temperature of soil surface to change rapidly and is closely related to relative soil moisture. The calculation formula of soil thermal inertia is:

$$P = \sqrt{K\rho C} \tag{1}$$

Where P = the soil thermal inertia $(J \cdot m^{-2} \cdot K^{-1} \cdot s^{-1/2})$ K = the heat transfer coefficient $(J \cdot m^{-1} \cdot s^{-1} \cdot K^{-1})$ $\rho =$ the density $(kg \cdot m^{-3})$ C = the volumetric heat capacity of the soil $(J \cdot kg^{-1} \cdot K^{-1})$ (Wang Y J et al.,2014) Because this formula requires more parameters, the calculation is relatively complicated, and there are certain difficulties in practical application. Price (Price J C,.1985) proposed the concept of apparent thermal inertia in 1985, considering that the solar radiation incident under certain conditions can be regarded as For a constant, the formula for the apparent thermal inertia can be simplified as:

$$ATI = (1 - A)/\Delta T \tag{2}$$

Where ATI = the apparent thermal inertia

A = the full band albedo

 ΔT = the maximum temperature difference of the surface in the day

Retrieval of relative soil moisture using the ATI model is simple and convenient, but only suitable for bare soil and low vegetation coverage, and does not take into account the effects of surface evaporation(Cai G Y, 2006).

3.1.2 Temperature Vegetation Dryness Index Method

Price et al(Price J C., 1990; Carlson T N et al., 1994) found that the scatter plots obtained by remote sensing data with the vegetation index as the abscissa and the surface temperature as the ordinate are triangular. Sandholt et al(Sandholt I., et al., 2002) studied the simplified LST-NDVI triangle space and found that there are many contours in the feature space of LST-NDVI, and the concept of temperature vegetation drought index (TVDI) is proposed. Based on previous researches, Wang Xinghan (Wang X H et al, .2017) used EVI instead of NDVI to construct TVDI based on irregular polygon feature space. This method overcomes the defects and characteristics of temperature vegetation index model which is prone to vegetation index saturation in high vegetation coverage area. The lack of correlation between the dry and wet edges of the space improves the retrieval accuracy of the relative soil moisture in the high vegetation coverage area. The TVDI model calculation formula is:

$$TVDI = \frac{LST_i - LST_{min}}{LST_{max} - LST_{min}}$$
(3)

Where LST_i = the surface temperature of any pixel

 LST_{max} , LST_{min} = the minimum and maximum surface temperature corresponding to a certain EVI value, that is, the dry and wet edges of the feature space.

It can be determined by polynomial fitting regression analysis to extract dry and wet edges. The dry-wet edge equation for polynomial fitting can be expressed as:

dry edge:
$$LST_{max} = \alpha_1 EVI^n + \alpha_2 EVI^{n-1} + \alpha_3 EVI^{n-2} + \dots + \alpha_n EVI^1 + \alpha_0$$
 (4)

wet edge:
$$LST_{min} = \beta_1 EVI^n + \beta_2 EVI^{n-1} + \beta_3 EVI^{n-2} + \dots + \beta_n EVI^1 + \beta_0$$
 (5)

Where α_0 , α_1 , α_2 , α_3 , ..., α_n ; β_0 , β_1 , β_2 , β_3 , ..., $\beta_n =$ polynomial fitting coefficients n = the number of times the polynomial fits, n is 2

It is simple and convenient to use the TVDI method to invert the relative soil moisture of the, but it is only suitable for medium and high vegetation coverage.

3.2 Establishment Of Retrieval Model

3.2.1 EVI Threshold Partition

Using the apparent thermal inertia model ATI and the temperature vegetation drought index TVDI model to jointly invert the surface soil moisture method. According to the temporal and spatial variation characteristics of EVI vegetation coverage in Guangxi Province, the EVI partition is used to invert the relative soil moisture. In the literature, NDVI=0.2 or 0.3 is determined as the partition threshold. In this paper, the remote sensing interpretation of the TM8 images from January to December 2017 and the corresponding EVI is analyzed by Google Earth Engine Platform (GEE). The threshold is found to be EVI= 0.33, then the relative soil moisture was retrieved by the normalized vegetation drought index (TVDI) method in the EVI>0.33 region, and the relative soil moisture were retrieved using the apparent thermal inertia model (ATI) in the EVI < 0.33 region. According to the temporal and spatial variation characteristics of vegetation coverage characterized by EVI in the study area, the EVI division is determined for January-February, April, and November-December; Among them, in June, the quality of remote sensing image imaging was not good due to weather, which was not conducive to the calculation of ATI and TVDI models, so it did not participate in relative soil moisture retrieval in June; In March, May, July, August, September, and October, the TVDI model was used alone to invert the relative soil moisture of the because the area occupied by EVI ≤ 0.33 was small (less than 5%). The TM8 data is selected. After the correction of the radiation, the bands with different cross-correlation and independent bands can be distinguished. The band 6, 5 and 4 bands of vegetation and non-vegetation can be distinguished well. Supervised classification is carried out after image enhancement. Combine with Google Maps and select a representative training field on the image (the number of training samples in the vegetation area is 100, and the number of training samples in the non-vegetation area is 100). After the separation test, the maximum likelihood method is used for classification.

3.2.2 Elevation Difference Correction Of Surface Temperature

In addition to the two major factors of soil temperature and surface vegetation enhancement, TVDI retrieval, other surface parameters such as roughness, albedo, etc., atmospheric conditions have an impact on the accuracy of the retrieval. Therefore, different solar radiation and atmospheric forcing conditions in different regions will affect the retrieval accuracy. Therefore, the paper corrects the surface temperature according to the difference in ground elevation, and the elevation correction formula is as follows:

$$LST_d = LST_S + H * a \tag{6}$$

Where LST_d = the surface temperature corrected by DEM LST_S = the surface temperature before correction H = the DEM value a = the correction coefficient, indicating the extent to which the surface temperature decreases with increase of

altitude. a value -0.06 ° C / 100 m (Qi S H et al.,2003)

3.2.3 ATI Model Parameter Calculation

According to the calculation formula for apparent thermal inertia (2), it is necessary to solve the full-band albedo and the maximum temperature difference between the surface and day and night ΔT . The full-band albedo A is obtained from the reflectivity of the ground objects wavelength $0 \sim \infty$, and is an important parameter for solar radiation to reach the earth's surface for redistribution. Because solar radiation is mainly concentrated on a narrow range of 0.25-1.5 m, the reflectance of visible light and near-infrared is approximated to represent the full-band albedo. The paper uses a wide-band albedo calculation formula for MODIS data(Liang S L.,2000):

$$A = 0.16\varphi_1 + 0.291\varphi_2 + 0.243\varphi_3 + 0.116\varphi_4 + 0.112\varphi_5 + 0.081\varphi_7 - 0.0015$$
(7)

Where A = broad band reflection

 φ_1 , φ_2 , φ_3 , φ_4 , φ_5 , φ_7 = the reflectance of the respective bands of the MODIS product.

The temperature difference between day and night and wide-band albedo are supported by the GEE technology platform and JAVA programming.

3.2.4 TVDI model parameter calculation

Supported by GEE, ENVI and MATLAB technology platforms, with the EVI threshold of 0.01, the maximum and minimum surface temperatures of the corresponding pixels are extracted, and LST_{max} , and LST_{min} are linearly fitted, and TVDI is calculated according to formula (3).Since the EVI value is less than 0, the composition is mainly water and cloud, and the moisture is 100%. When the EVI value is 0 to 0.2, the surface components are mainly urban buildings and hardened ground. When the dry and wet edge fitting are performed, the pixels of this part are not considered, and the value of EVI < 0.2 is excluded, and only the EVI which is in the medium-high vegetation area and the proportion of the pixels is selected .The EVI value is inverted using the maximum synthesis method, and the EVI of each of the two phases is synthesized into the monthly EVI.

3.2.5 Retrieval and Synthesis Of Relative Soil Moisture

A linear model is established by comparing the ATI value or TVDI value of the sample pixels in the study area with the measured relative soil moisture data by using the least squares method,, and then the relative soil moisture value of the study area is inverted. The model formula is as follows:

$$W = a_1 + b_1 \times ATI \tag{8}$$

$$W = a_2 + b_2 \times ATI \tag{9}$$

Where W = the relative soil moisture value measured at depth of 10 cm

 a_1, b_1, a_2, b_2 = regression model coefficients

4. RESULTS AND ANALYSIS

4.1 Relative Soil Moisture Retrieval Model Fitting Results

According to the monthly EVI, the vegetation coverage rate of Guangxi was divided, and then the ATI values or TVDI value of each month of 2017 and the measured relative soil moisture value of 10 cm depth was regression-fitted by least squares method. During the fitting process, the measured abnormal values of relative soil moisture are excluded. The regression model was statistically tested, and the fitting results of each month passed the hypothesis test with confidence of 0.01 (Table 2), and the simulation results were better.

Month	Soil depth(cm)	model	Fitting equation	R ²	F
1	10	TVDI、 ATI	y = -0.6333x + 1.1589	0.25	6.7118
2	10	TVDI、 ATI	y = -0.9485x + 1.2737	0.24	6.2064
3	10	TVDI	y = -0.2159x + 1.0388	0.16	1.1796
4	10	TVDI、 ATI	y = -0.1367x + 0.9706	0.12	3.28423
5	10	TVDI	y = -0.1485x + 1.0073	0.14	3.78781
7	10	TVDI	y = -0.4144x + 1.2291	0.17	4.0899
8	10	TVDI	y = -0.2302x + 1.0771	0.15	3.98448
9	10	TVDI	y = -0.0726x + 0.8764	0.11	3.10604
10	10	TVDI	y = -0.164x + 0.9424	0.12	3.44826
11	10	TVDI、 ATI	y = 0.1312x + 0.8217	0.14	3.89462
12	10	TVDI、 ATI	y = -0.1789x + 0.8478	0.12	3.35008

Table 2. Fitted ATI and TVDI models of monthly relative soil moisture in Guangxi and the significant test results

From Table 2, it is shown that in the first and second months, the joint model and the relative measured soil moisture regression fit better than other months. The decision coefficient R^2 of the remaining months is greater than 0.1.The monthly decision coefficients in the table indicate that the ATI-TVDI joint model is more correlated with relative soil moisture than the ATI or TVDI model alone.

4.2 Analysis Of Retrieval Results

According to the National Meteorological Department (NWSPR ,2005.) on the classification of drought levels for remote sensing of relative soil moisture, using the above-mentioned fitting model and synthesis method, the retrieval results of the relative soil moisture values in Guangxi in 2017 were obtained (Figure 2), and the average relative soil moisture trends in each month are shown in Figure 3 (Figure 3).



Figure 2. Relative soil moisture in Guangxi from January to December in 2017 (from left to right, from top to bottom)



Figure 3. Average relative soil moisture in Guangxi in each month of 2017

From Figure 2, the spatial distribution of relative soil moisture in the study area is characterized as follows: First, due to the spatial difference of annual precipitation, the relative soil moisture in Guibei area with relatively large annual precipitation and large vegetation coverage is higher than that in Guizhong and Guinan. Due to the abundant water vapor in the area with high vegetation coverage, the annual cloud amount is large in the area, and the acquired remote sensing image data is not well imaged; Second, most of the plants in the Guizhong area were harvested in autumn, and the area of bare land increased, making the relative soil moisture slightly lower than that in the northern part of Guangxi. Third, the relative soil moisture in Guidong and Guixi areas changed synchronously.

According to Figure 3, the temporal variation on the relative soil moisture in the study area in 2017 shows a period of change of rising to falling: The rising period is from January to July,

and the falling period is from August to December, with July reaching its peak and the minimum appearing in December. It just happened to rise in the second half of the year. The above-mentioned relative soil moisture change law is consistent with the annual variation of precipitation and air temperature.

4.3 Accuracy test of relative soil moisture retrieval model

In order to test the feasibility and accuracy of the retrieval of relative soil moisture in this paper, one month is selected from the representative spring, summer, autumn and winter seasons. The relative soil moisture values of the retrieval and the measured relative soil moisture values of 22 meteorological stations were tested point-to-point (Table 3), and the soil moisture contrast residuals of each meteorological site are shown in Figure 4 (Figure 4).



Figure 4. Relative soil moisture residuals for the typical month of 2017

Month	Number of samples	Maximum error(%)	Minimum error(%)	Average relative Error(%)
1	22	17	1	8
4	22	28	1	10
7	18	18	1	6
11	21	17	1	6

Table 3. Verification accuracy of relative soil moisture residuals models in representative months in Guangxi

Figure 4 shows that the absolute values of relative soil moisture residuals in January, April, July and November 2017 are stable within 0.1%. The difference between the relative soil moisture value of the joint model retrieval and the measured relative soil moisture value is small. It can roughly reverse the actual relative soil moisture. Among them, Nanning and Qinzhou stations, the relative soil moisture retrieval in April was slightly

larger than the measured relative soil moisture, and the residual values were all greater than 0.1.Looking for the weather data of the current month, the weather in the two stations was mostly cloudy, and the obtained ground temperature data had errors. Therefore, the relative soil moisture of the joint model retrieval differs greatly from the measured relative soil moisture.

From the results of Table 3 test, the average relative error of January, April, July, and November 2017 is basically consistent with the research conclusions of other scholars(Di L J et al., 2014). The month with the largest retrieval of soil moisture error in the model is April, the maximum error value is 28%, and the average relative error of relative soil moisture in each typical month is below 10%. Explain that the retrieval results are consistent with the measured temporal and spatial distribution of soil moisture.

5. CONCLUSION

Taking into account the advantages and disadvantages of the ATI model and the TVDI model, when retrieval of the relative soil moisture in Guangxi in 2017, the relative soil moisture retrieval was performed using the EVI zoning method in January-February, April, and November-December. The TVDI model was used in the region with EVI>0.33 in the month, the relative soil moisture in the EVI < 0.33 region was inverted using the ATI model, and the TVDI model was used to invert the relative soil moisture in March, May, and July-October. In June, due to poor image quality of remote sensing images, it did not participate in relative soil moisture retrieval. Among them, the temporal variation of relative soil moisture in the study area in 2017 shows the change cycle from rising to falling: the rising period is from January to July, and the peak is reached in July, and the falling period is from August to December, just in the first half. The rise in the second half of the year is lower; the relative soil moisture in the northern part of Guangxi is generally higher than that in southern Guangxi. The study found that the correlation between the relative soil moisture value and the measured relative soil moisture data of the ATI model and the TVDI model partition retrieval is higher, and the retrieval results are closer to the temporal and spatial changes of the actual relative soil moisture in the study area.

The measured relative soil moisture data is point data, and the remote sensing retrieval parameters such as apparent thermal inertia and temperature vegetation drought index are 1km x 1km surface data, and there is spatial scale difference between them; The measured relative soil moisture data is based on the daily data of the 5-day monitoring (1st, 6th, 11th, 16th, 21st, and 26th of each month), which represents the average of each month, and it will produce timescale differences with the remote sensing retrieval parameters. The above factors will affect the accuracy of the retrieval. In the future research, it is necessary to further explore methods for eliminating scale differences and more accurate retrieval methods without ground monitoring data constraints.

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