An Improved Method for Monitoring of Soil Moisture Using NOAA-AVHRR Data

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Abstract: Soil moisture is a crucial variable in research works of hydrology, meteorology and plant sciences. Adequate soil moisture is essential for plant growth; excesses and deficits of soil moisture must be considered in agricultural practices. There are already several remote sensing methods used for monitoring soil moisture, such as therma l inertia, vegetation water-supplying index, crop water stress index and multi-factor regression. In this paper, an improved method has been discussed which is based on the thermal inertia. We analyzed the problems of monitoring soil moisture using satellites at first, and then put forward an simplified method which directly uses land surface temperature differences to measure soil moisture. Also we have taken the influence of vegetation into account, and import NDVI into the model. The method was used in the study of soil moisture in Heilongjiang Province, China, and we draw the conclusion by the experiments that the model can evidently increase the precision of monitoring soil moisture.
Keywords: soil moisture; thermal inertia; NDVI

1. Introduction

Soil moisture, which infecting directly the growth of crops, is the best infective index of reflecting the development tendency of drought. Calculating soil moisture using remote sensing data springs up with the development of the detecting satellites in recent years and has made some process. Now, the data of monitoring soil moisture using satellite remote sensing are mainly from meteorological satellites, such as Landsat and the National Oceanic and Atmospheric Administration(NOAA) Advanced Very High Resolution Radiometer(AVHRR) in monitoring the large areas.

There are several methods for soil moisture derivation from AVHRR data, such as Thermal inertia method, Water supplying vegetation index, Anomaly vegetation index, Vegetation condition index, Vegetation drought index and etc. But those methods are still experimenting and cannot yet be used routinely. However some of those have been used routinely according to the information home and abroad, their practicability are restricted to some extent because many rigid limitation and related factors need to be considered. Based on the principles of thermal inertia and on consideration of vegetable cover, a new drought remote sensing model is developed and some experiments have been made to verify the approach. It was demonstrated that the method provides a fairly good result in the area in Heilongjiang Province, China with mass vegetation cover in summer and autumn time.

2. Thermal Inertia Method

2.1 The principle of Thermal inertia method

This method is based on the principle that soil moisture is directly proportional to thermal inertia. Thermal inertia can be derived from AVHRR data using the following formula:

$$TI = c \cdot (1-A)/(T_{day}-T_{night})$$

Where, c is a experimental coefficient, related to soil type. A is the albedo of land surface, calculated as:

$$A=0.526*CH1+0.47*CH2$$

T_{day} and T_{night} are respectively the maximum and the minimum value that the surface temperature assumes during the diurnal cycle with the regions bare covered with vegetation, derived from CH4.

$$TIp = \frac{T_{day} - T_{night}}{1 - A}$$

In the face operations, in order to simplify the calculation, the most common method is to establish directly the relational function between soil moisture(SW) and temperature difference($\triangle T = \boldsymbol{T_{day}} - \boldsymbol{T_{night}}$). This function can be established by regression method as SW=F(△T).

$$SW = a \bullet \triangle T + b$$

where, a and b are the regression coefficients.

2.2 The limitations of Thermal inertia method and the solutions

Thermal inertia method has been used widely all over the country, but still exists many limitations especially in the scope of application. Firstly, the method is efficient only in the area with less vegetation cover, because vegetation cover reduce the temperature difference between day and night, the relationship between thermal inertia and soil moisture is not so close. Secondly, the method is efficient only with cloud-free images available both in day and night because to detect the soil moisture situation in a certain place and a certain time, the temperature difference derived from AVHRR/CH4 is needed. But it's not easy to get cloud-free AVHRR images both in day and night in the same day if the area is quite large, so this method can not be used in real-time monitoring.

In this paper, we adopt an improved thermal inertia method on the basis of former research, which can extend the model's application scope to great extent. In addition, we use the temperature difference between morning and noon to replace the one between midnight and noon when lacking of the satellite data in the midnight. After the experiments in Heilongjiang province, the above approaches are proved to be quite feasible in monitoring summer drought in cultivated area.

3. Improved Drought Model

When detecting drought information by using meteorological satellite data, what we care about is how drought influence agriculture. So the most drought monitoring time is in later spring, summer and autumn. In the thermal inertia model, $\triangle T$ is only the temperature difference of the land surface where is covered with less vegetation. As we know, when the land surface is covered with vegetation, NDVI increases and the temperature difference between the day and the night decreases. So we use NDVI to correct the temperature difference in the formula of the thermal inertia as following:

$$SW = a + b \ \triangle T'$$
$$\triangle T' = NDVI/k + \triangle T$$

The lower are the values of NDVI the higher is $\triangle T$ from the satellite data and $\triangle T$ is closer to $\triangle T'$. when the detected area is non-covered with vegetation, the values of NDVI are zero and $\triangle T$ is equal to $\triangle T'$.

4. Experiments

The investigated area is Heilongjiang province and concerns of 26 soil stations. The remote sensing meteorological data are NOAA and FY-1 digital type of July 8, 2002 and September 29,2002. The field measurement data are provided by Institute of Water Resources Research of Heilongjiang province. The meteorological data must be pretreated such as geometrical correction, atmospheric disturbances correction and cloud-detection etc before they are used.

Using Thermal Inertia Model and the improved model mentioned above, we abstained the values of the coefficient, including a, b and K, by establishing the relation between the relative water content of soil of different depth and land surface temperature difference and NDVI, and do some compare between the two models. Here are two group experimental data to prove the proposed solutions.

The following Table 1 shows the calculating results by meteorological data on July 8, 2002 and $\triangle T$ is derived from the land surface temperature difference of NOAA data between 2:00 and 13:00 AM GMT.

Table 1. Comparison of the calculating results between thermal inertia model and the improved thermal inertia model on July 8, 2002

model	depth	SW	r
Thermal inertia model	10cm	86.6987-1.3488X	0.77683
	20cm	97.5336-1.515X	0.7515
The Improved model	10cm	89.8899-1.4270X	0.78597
	20cm	102.0158-1.6533X	0.78424

The experimental meteorological data of the second group is received on September 29,2002 and $\triangle T$ is derived from the land surface temperature difference between NOAA data at 2:00 and FY-1 data at 13:00 AM GMT. Table 2 shows the calculating result.

Table 2. Comparison of the calculating results between thermal inertia model and the improved thermal inertia model on September 29, 2002

model	depth	SW	r
Thermal inertia model	10cm	113.1583 - 5.0152 X	0.71851
	20cm	116.4616 - 4.5412 X	0.60226
The	10cm	116.4597 - 5.1466 X	0. 83439

Improved model	20cm	119.3634 - 4.6521 X	0. 69817

The distribution maps of soil moisture in the study region are showed as following. In these maps, the color table indicates different soil moisture situation. Red color means below 40%, light red means 41~60%, pink means 61~70%, light green means 71~80%, green means beyond 81% and white means that the area is cloudy or lacking of data.

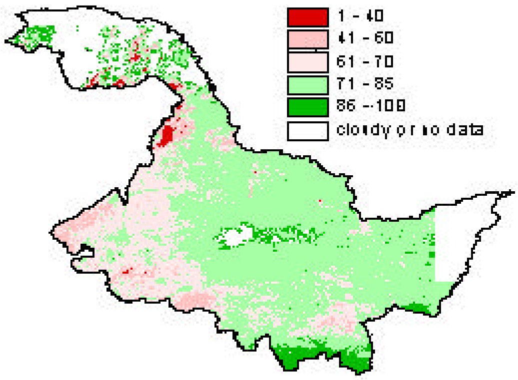

Fig.1 Soil Moisture (Relative Value) Remote sensing Monitoring map on July 8, 2002

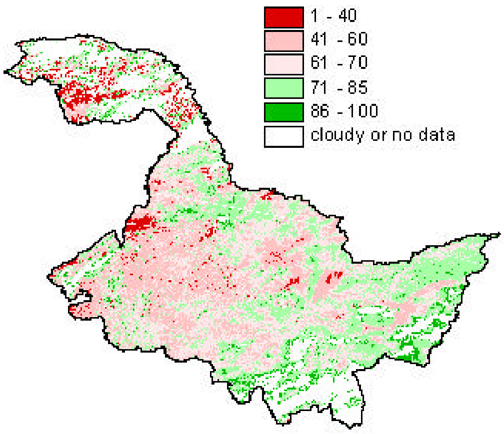

Fig.2 Soil Moisture (Relative Value) Remote sensing Monitoring map on September 29, 2002

The results show that the improved method is more precise no matter that the soil layer depth are 10cm or 20cm, and it can meet the need of precision by using the temperature difference between morning and noon instead of the one between midnight and noon.

5. Conclusions

The improved thermal inertia model provides an efficient method to monitor the area with vegetation cover, and extends the application scope of thermal inertia model. Based on the improved model, we get the surface temperature differences by combining NOAA with FY-1 data to increase greatly the usability of digital images. However, it is much more difficult to monitor soil moisture using meteorological satellite remote sensing data in Heilongjiang province because the underlying surface is more complicated in this region. Therefore, it is required to be verified by a large amount of work.

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