DETECTING SOIL MOISTURE UNDER CANOPY
BY MEANS OF NOAA AVHRR

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ABSTRACT

Handan Municipal Region in Hebei province of China was chosen as study area. Both insitu observed data (i.e. soil moisture S_m, canopy temperature T_c, air temperature T_a and soil surface temperature T_s) and NOAA AVHRR data were collected simultaneously from 11 sample stations within this area during one year period (1990). All of the NOAA AVHRR different channel data and insitu measured data were used in correlation and regression analysis. Theoretical temperature differential method using NOAA AVHRR thermal band data T_{nc} as the canopy temperature, insitu measured air temperature and soil moisture was applied in comparing correlation and regression models among them at the beginning stage. NOAA AVHRR data and insitu collected soil moisture data were also used in determining the correlation coefficients and regression model with the modification of vegetation index data which were obtained by using of NOAA AVHRR channel one and channel two data at the final stage. The results show that using brightness temperature obtained from AVHRR channel 3, channel 4 and Soil moisture have a very significant correlation with the modification of the vegetation index in day time. This correlation is more significant than the former method (using T_{nc}, T_a and S_m) with correlation coefficient of -0.88. The reason of the deviation of these two method is also analyzed in this paper. This method for monitoring soil water contents is the most feasible way which has not been found both in China and other countries. It has a significant use in agriculture activity.

Key words: Soil Moisture, NOAA AVHRR, Remote Sensing

1. INTRODUCTION

Soil moisture is an important factor for crop productivity, specially for crop production in North of China. Crops are suffering from water deficiency and its yields are reducing. Therefore, the assessment of soil moisture becomes an essential requirement. From remote sensing data, it may be possible to make a quick assessment of soil moisture in vast areas. The possibility of using satellite data to understand energy and moisture fluxes at the earth's surface has been recognized previously (Wiegand and Namaken 1966; Idso *et al.* 1975; Musick and Pelleter 1986; Liu 1987; Price 1980). NOAA series of polar-orbiting satellites (after TIROS N) have acquired good quality visible and infrared data at 1 Km spatial resolution with appropriate characteristics to such kinds of studies. The potential of remotely sensed thermal data are useful for assessing the moisture budget (Price 1980). Thermal inertia method for determining soil moisture is essential with its clear physical meaning (Price 1980). However, this method depends on several insitu observed parameters such as minimum and maximum temperature of soil surface (Liu 1987a), which may limit its practical application. These maximum and minimum temperature should be observed in the same day (Liu 1987a).

Differential of soil surface temperature obtained from NOAA AVHRR thermal data and that of air observed insitu could also be used in monitoring its moisture (Liu 1987b). However, there should be some difficulties to collect the temperature of air from place to place. These may also affect the possible frequency to monitor soil moisture on real time.

The objective of the present study is to find out a more feasible model without considering insitu observed data to detect soil moisture under canopy by means of NOAA AVHRR remotely sensed data. These data should be visible or infrared and related to soil moisture.

2. METHODS

2.1 Study Areas and Data Collection

Handan Municipal Region in Hebei Province were chosen as the study areas, which is

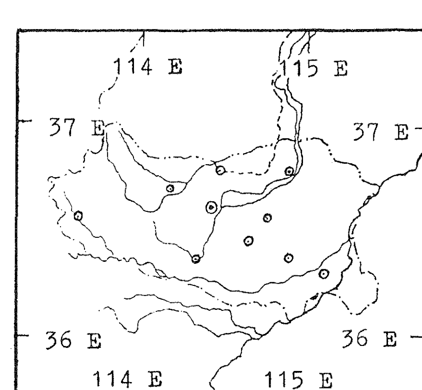

Figure 1. Study area of Handan

located approximately at longitude between 113°30' - 116°30' E and latitude between 36°05'-37°01' N and includes four counties (Fig. 1). In this study area, total of 11 sample stations with different soil type or different vegetation density were selected for getting insitu data. These insitu data include soil moisture, temperature of canopy, temperature of air and weather conditions. Simultaneously, NOAA AVHRR data (NOAA 10, 11) were also collected from NOAA satellite ground receiving station. All these insitu data observation were conducted during 1 April to 31 October with 5 day interval in 1990.

Sample stations were selected on the bases of three different soil types and soil textures. All absolute soil water contents were converted to relative water contents from the depth of 0 to 5 cm.

2.2 Theory and Data Analysis

Wavebands of NOAA AVHRR ranges from 0.65-12.5 µm (Table 1). NOAA AVHRR middle infrared

Table 1 NOAA AVHRR Wave Band Compared with Landsat TM

AVHRR		TM	
channel	waveband (µm)	channel	wave band (µm)
		1	0.45-0.52
		2	0.52-0.60
1	0.58-0.68	3	0.63-0.69
2	0.73-1.10	4	0.76-0.90
		5	1.55-1.75
3	3.53-3.93	7	2.08-2.35
4	10.30-11.30	6	10.40-12.5
5	11.50-12.50		

(reflective infrared) channel 3, according to its characteristics in day time, receives the energy from the ground objects that should contain two parts. One of them is objects radiation energy and another is sun energy reflected by objects, which can be expressed as following:

$$E_3 = E_{31} + E_{32}$$
$$= \int \varepsilon A(T, \lambda)\, d\lambda + \int \rho L(\emptyset, \theta) \cos\emptyset \sin\theta \, d\emptyset d\theta \qquad (1)$$

where

E_3 total energy received by AVHRR channel 3
E_{31} radiation energy received by sensor
E_{32} reflective energy received by sensor
ε object emissivity
T object absolute temperature
λ wavelength
ρ reflectance
θ zenith angle
$\emptyset$ azimuthal angle
$L(\emptyset,\theta)$ **solar irradiance at zenith angle θ** and azimuthal angel $\emptyset$

However, according to their characteristics and Planck's radiation law, thermal channel 4 and 5 of NOAA AVHRR receives energies that only contain the ground objects radiation energy (here, for simplifying the problem, atmospheric affection were not considered). These received energy can be represented as follows:

$$E_4 = \int \varepsilon A(T, \lambda)\, d\lambda \qquad (2)$$

$$E5 = \int \varepsilon A(T, \lambda)\, d\lambda \qquad (3)$$

where,

E_4 radiation energy received by sensor
E_5 radiation energy received by sensor
ε object emissivity
T object absolute temperature
λ wavelength

Among these functions, all radiation emissivity are depended on the texture of different objects. The important factors which affect the radiation emissivity of objects are the soil texture and moisture (water contents). The radiation emitance is 0.92 for dry soil and 0.95 for wet soil (Ji 1979). From these views, it may be possible to detect soil moisture using the NOAA AVHRR remotely sensed data.

Figures 2, 3, 4 also give clear concepts about the relations between soil moisture and spectral reflectance properties. From these figures it can be concluded that the lower the soil moisture, the higher the reflectance.

Further more, deficiency of soil water content can reduce the transpiration rate of plant and cause its temperature to rise (Wiegand and Namaken 1966). The differential of maximum temperature of air and canopy has a good linear correlation with moisture of soil under canopy (Schmugge *et al.* 1977).

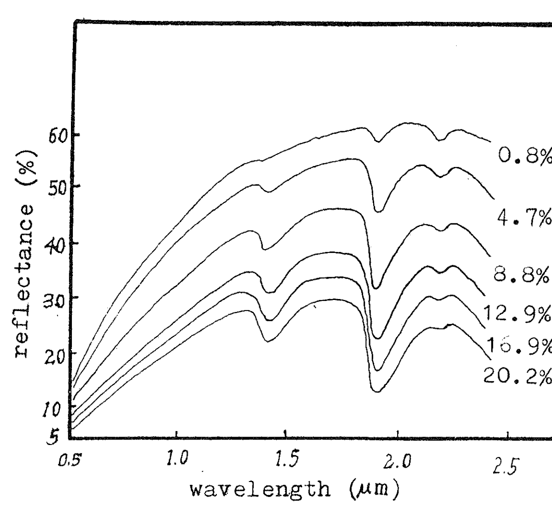

Fig. 2 reflectance of Chelsea sandy soil with different water content (Bowers **1965**)

From all above discussions, it can be concluded that the soil moisture may be estimated from NOAA AVHRR received radiation and reflective data.

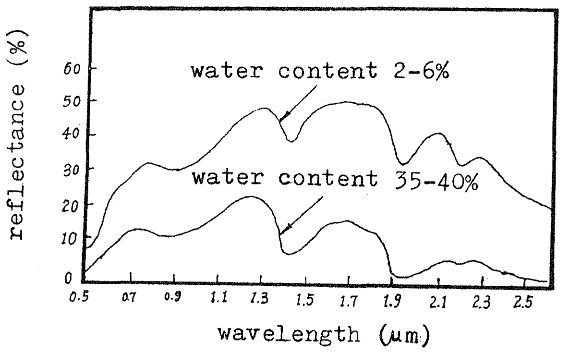

Fig. 3 Reflectance of Newtonia sandy clay Soil with different water content (Swain 1978)

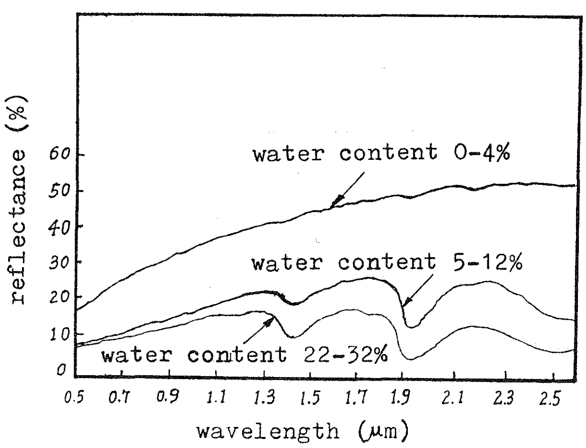

Fig. 4 Reflectance of Pembrock clay soil with different water content (Bowers 1965)

However, the roughness of the observed objects (soil) also affect their emissivity and reflectance. For the surface roughness of objects (soil) under canopy, vegetation density is a important factor which can be obtained from NOAA AVHRR channel 1 and channel 2 data using an indicator of Vegetation index. The equation used for vegetation index calculation of AVHRR channel 1 and 2 can be:

$$V_i = SQRT[(ch_2 - ch_1)/(ch_2 + ch_1)] \qquad (5)$$

where,

V_i vegetation index,
SQRT square root of,
Ch_n NOAA AVHRR received reflective data.

This index can be used to modify the correlation coefficient of the regression model.

Now, the soil moisture may be detected by means of NOAA AVHRR received reflective data of channel 3 and compared with the insitu real time relative moisture data modified by vegetation index. This received reflective data can be estimated from total received data of channel 3 (daytime) substracted by the modified thermal radiative data of channel 4 or 5. The model can be simplified as:

$$S_m + V_i = A + B * (E_3 - E_n) \qquad (6)$$

where,

S_m relative soil moisture,
V_i vegetation index,
A,B constant,
E_3 total received energy of AVHRR channel 3,
E_n radiation energy received by channel 4 or 5 of NOAA AVHRR.

All the satellite NOAA AVHRR data and insitu data taken simultaneously were considered in this study. However, the total number of samples of simultaneously obtained insitu data were not sufficient, and so, one day or two day bias near real time data were chosen in this analysis. Total twenty eight records of samples were used for building model in this study. Remaining data were taken for proving the model. These samples were acquired during the period of April 15 to October 31, 1990.

NOAA AVHRR and insitu data were processed and analysed using a IBM PC based compatible microcomputer. All software were developed by author using Pascal computer language that increase the flexibility of digital image processing and statistical analysis of these sample data. Firstly, radiation data of NOAA AVHRR channel 3, 4 and 5 were converted to brightness temperature and dumped on screen according to insitu observed sample locations. Satellite detected soil surface temperature using channel 4 and 5 were calculated. For soil surface temperature calculation, the sea surface temperature model was used (Kidwell 1985). These data were taken into sample data file as parameters. Secondly, the vegetation index were calculated in the same software package and set these vegetation index values to corresponding insitu observed sample locations. Finally, the obtained sample data set were analysed statistically (i.e. correlation coefficient, regression and ANOVA analysis).

3. RESULTS AND DISCUSSION

Various combinations of the data set were analysed that gives several different results. The best result has been found using the arithmetic model:

$$\ln(S_m) = A + B * [(T_3 - T_n) + SQRT(2*V_i)] \qquad (7)$$

where,

T_3 Brightness temperature of channel 3
T_n Brightness temperature of channel 4

A 5.2135
B -0.0793

The correlation coefficient between logarithm of insitu soil water content and that of estimated soil moisture data is 0.91 with significant value less then 0.002.

Figure 5 and 6 show the relation between t3-t4 (dt34) and relative soil water content. The reason of logarithm regression is that there is an exp conversion from received energy to brightness temperature.

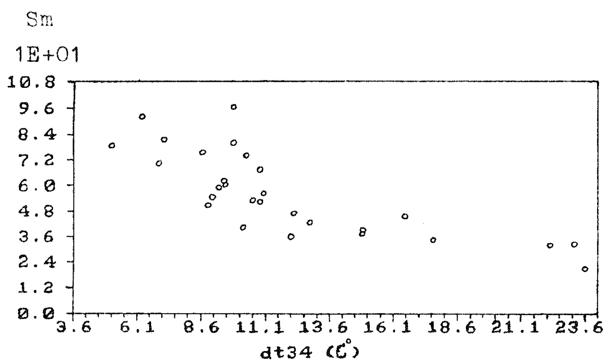

Fig. 5. Scattergram of AVHRR Channel 3 and 4 Daytime Brightness Temperatures Difference (Channel 3 Received Reflective Radiance) to Sm

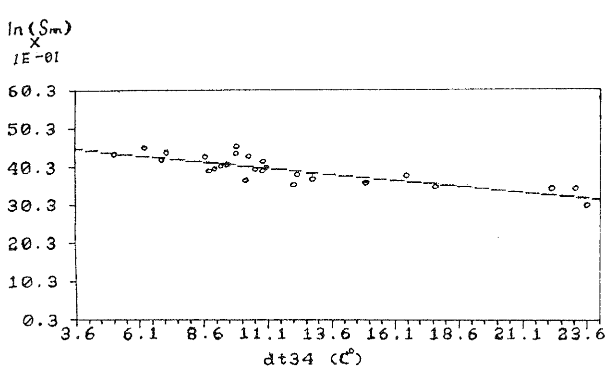

Fig. 6. Scattergram of AVHRR Channel 3 and 4 Daytime Brightness Temperatures Difference (Channel 3 Received Reflective Radiance) to ln(Sm)

From Figure 5, it may also be said that the correlation coefficient will be better without the effect of one day or two day bias data. All time bias insitu data were collected either due to weather condition or manpower insufficient. After modification of these data, the correlation will be a little bit better. However, because of the precipitation, collection of actual soil moisture data from place to place are difficult. And so, it is difficult to conduct the one day or two day bias insitu data modification.

When the detected object (soil) is under canopy, in some cases, the roughness of objects surfaces may be submitted by vegetation index. Figure 7 shows the relation between vegetation index and the regression of soil water content (logarithm) and dt34. From this figure, it can be found that vegetation index value are decreasing across the regression line. This can be used to modify the reflectance of object. Modification of using vegetation index obtained from NOAA AVHRR channel 1 and 2 has increased the correlation coefficient of this analysis model(Fig. 8). This result proved the theory that the NOAA AVHRR different channel received reflective or radiance data are not only affected by soil moisture but also the vegetation density when the objects under canopy. The result after modification by use of vegetation index has increased the correlation coefficient from 0.84 to 0.88.

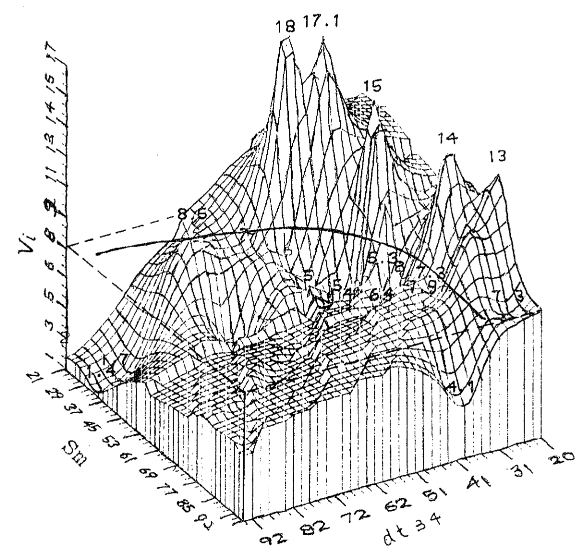

Fig. 7. Relationship between Vegetation Index (Vi) and Regression of AVHRR Ch. 3 and 4 Daytime Brightness Temperature Difference (dt34) to Sm

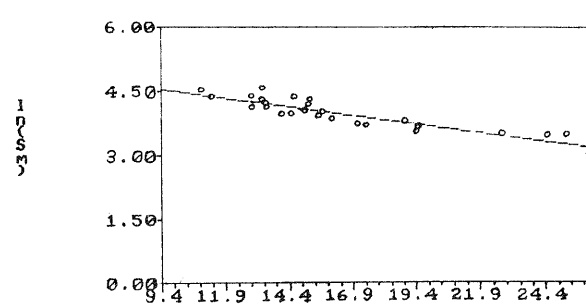

Fig. 8. AVHRR Channel 3 Received Reflective Radiance (dt34, daytime) plus SQRT(2*Vi) to ln(Sm)

Thirteen records insitu soil moisture data were used for proving the model built in this study. The natural logarithm of insitu collected soil moisture and that calculated by the model have a satisfied correlation coefficient value and pass the significant test.

These results strongly support the theory used in this study. This method of soil moisture detection will not depend on several insitu observed data such as temperature of canopy and air or the maximum and minimum temperature in one day. Thus, it can be said that this method may be a little bit more feasible for monitoring soil moisture under canopy.

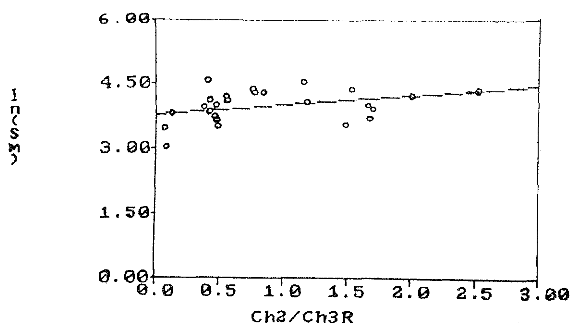

Fig. 9. AVHRR Ch2/(Ch3-Ch4) Bidirection Reflectance Ratios to ln(Sm)

The result of band ratio of NOAA AVHRR channel 2 and reflective part of channel 3 (Fig. 9) support the idea of that (Price 1980) of Landsat TM4 and TM7 (TM_4/TM_7). Even the wavelengths of NOAA AVHRR channel 2 and 3 and Landsat TM_4 and TM_7 are not exactly the same.

The result of statistical analysis using differential of soil surface and air temperature is not satisfied because of the deficiency of sufficient real time data. Another reason may be that it is difficult to find a suitable temperature calculation model for different type soil by using AVHRR. Moreover, the use of single channel brightness temperature instead of the real canopy temperature may also bring some deviation since the radiation energy received by AVHRR varies with different vapour content in atmosphere.

The programs used in this study have also been developed for calculating soil moisture and depicting its distribution map either in form of digital or image on this system.

This study for monitoring soil moisture by means of NOAA AVHRR without considering any insitu observation data must be very useful for agriculture activities. Further study for detecting soil moisture should focus on obtain more data to improve this model.

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