RESEARCH ON DYNAMIC DROUGHT MONITORING METHOD BASED ON REMOTE SENSING AND PRECIPITATION INFORMATION

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KEYWORDS: Remote Sensing, Precipitation, Soil Moisture, Drought Model, Correlation, Dynamic.

ABSTRACT:

There are great advantages in using multi-temporal, multi-spectral and hyperspectral remote sensing data for dynamically and macroscopically monitoring widespread land surface. Exercising this advantage, dynamically adaptive regional drought monitoring system is established, combined with meteorological and hydrological information based upon actual ground measurements for different regions and time domain. First of all, several important factors affecting soil moisture were investigated, as well as the relationship among these factors based on the mechanism and process of drought occurring. Then, work was carried out on the establishment of empirical drought model using statistical methods based on the drought evaluation factors, and to make dynamic correction and evaluation of the results by using soil moisture data based upon actual ground measurements. In order to verify the integrated model of drought proposed in this paper, regional integrated model of drought in time scale of ten days was established for Hubei and Hebei province in China. It showed that it is feasible to establish dynamic, real time, accurate, and adaptive regional drought monitoring model using remote sensing.

1. INTRODUCTION

China, which is located in the southeast of the mainland of East Asia, is the most prominent country affected by typical monsoon climate. Drought occurs frequently in China with uneven spatial and temporal distribution of precipitation. The sustainable development of society and economy is affected seriously by the frequent occurrences of drought. Evolving effective measures to monitor the drought and to minimize the losses caused by drought is the urgent problem in water and agriculture industry.

Traditional drought monitoring methods based mainly on soil moisture measurement of limited ground points is only suitable for coarse scale drought monitoring over a wide area, but not for quick and accurate monitoring. Remote sensing technology provides rich information for drought analysis. Common methods of monitoring drought by remote sensing include establishment of a time series of vegetation condition index, assessment of soil moisture by calculating the ratio of actual evapotranspiration and potential evapotranspiration, and establishment of thermal inertia of soil moisture model for drought monitoring etc. the methods that either involve complexity computation and many parameters or ignore the accuracy of hydrological and meteorological information with only using remote sensing data cannot achieve the goal of long term, dynamic and real time large scale drought monitoring and forecasting.

Due to the effect of a variety of factors, such as solar radiation, precipitation, topography and water vapour recycling etc., each method of drought monitoring cannot be completely suitable for different regions and time scales. With the development of remote sensing and geographic information systems technology, it is feasible to establish integrated monitoring model suitable for a variety of regions and time domains through combining different remote sensing indices with the information based upon actual ground measurements. In this paper, remote sensing and precipitation, as well as soil moisture data based upon actual ground measurements are combined to establish integrated drought monitor model for different regions and time domains through analysing and selecting the appropriate factors, armed to reasonably assess the drought situation in a specific area.

2. ANALYSIS OF FACTORS

The meaning of drought is a complex phenomenon, and 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 initial period. Drought can be understood as shortage of water supply or imbalance between the demand and supply of water. There are many factors affecting the drought, such as soil moisture, precipitation, land utilization, evaporation, temperature, planting structure, and water supply capacity of water conservation projects and so on, in which the precipitation plays a very important role, the intensity and duration of drought can be reflected by statistical distribution of precipitation. Precipitation reflects only water income of an area during a period, water demand in different areas or seasons are different. The extent of wet and dry conditions does not only depend on precipitation, but also relates to other important components in the water balance process.

In the process of water balance, soil moisture, surface heat, and surface evapotranspiration are closely related. Net radiation got at the earth’s surface is the starting point for a variety of heat exchanges, and forms of the energy distribution mainly include sensible heat flux for atmospheric warming, latent heat flux for the soil (or other underlying surface) warming. Additionally another part of the energy, which accounts for a negligible proportion of the total is consumed in the vegetation photosynthesis and biomass increasing.

Surface energy balance equation can be expressed by the following formula:

$$R_n = LE + H + G + PH \tag{1}$$

Where Rn= net radiation

LE= latent heat flux

H= sensible heat flux

G= land heat flux

PH= biomass energy consumption

We can see from equation (1), net radiation at the earth's surface after the radiation balance is converted into the formation of soil heat flux, sensible heat flux and latent heat flux, while the distribution share of them is closed with the soil moisture content. Due to the reduction of the water supply to ground vegetation cover, plant is stressed by water and will close leaf stomata in order to reduce transpiration, thereby lower the distribution of latent heat flux. According to the energy balance principle, it will lead to increasing of sensible heat flux and soil heat flux, and both of them change the temperature of the surrounding environment, further leading to increasing the land surface temperature. In contrast, because of strong transpiration and ground evaporation, most of the energy is used for latent heat consumption, the other two types of flux decline, so land surface temperature is reduced accordingly. It is obvious that the land surface temperature can be used as an index to reflect soil moisture. Vegetation index determines the land surface vegetation coverage. Vegetation produces different radiation balances under different surface coverages and the underlying surface receive different net radiation. Vegetation index also determines the information content of soil background and vegetation canopy from visible and thermal infrared reflection received by a remote sensor. Land surface temperature has a good correlation with the soil moisture, and can be used to make more accurate evaluation to regional drought only under the same conditions of the vegetation index.

In the above analysis, the rainfall data is obtained by measurement; surface temperature and vegetation cover conditions can be calculated using remote sensing data. This paper chooses the precipitation index and remote sensing index based on NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) as the drought evaluation factors.

3. SELECTION AND EVALUATION OF DROUGHT FACTORS

3.1 SPI (Standardized Precipitation Index)

There are two drought indices based on precipitation. One relates to the details in the various physical processes involved in drought by studying the mechanism of drought, such as the PDSI (Palmer Drought Severity Index). The physical mechanism of such indicators are relatively clear, but the calculation is complicated with more demanding information, and some parameters that cannot be obtained by experiments, rely only on empirical estimates, thereby the calculation accuracy is greatly reduced. The other one is used to study the statistical distribution of precipitation, in order to reflect the intensity and duration of drought by meteorologists. Computation of the indices is simple with available data, and they have good space-time adaptability because of not involving specific drought mechanism.

McKee et al. proposed SPI (Standardized Precipitation Index) based on precipitation when making the assessment of drought conditions in Colorado. The index reflects the intensity and duration of drought well. The same drought indicators to reflect the different time scales and regional drought conditions is possible, and therefore widely used. In calculating the SPI process, firstly the total precipitation is fit to probability distribution, and then the distribution is converted into the standard normal distribution. Finally, the SPI value of each time scale is established to define drought levels.

3.2 TVDI (Temperature-Vegetation Dryness Index)

In the NDVI-Ts feature space, TVDI (Temperature-Vegetation Dryness Index) calculation is as follows:

$$TVDI = \frac{T_s - T_{s-\min}}{T_{s-\max} - T_{s-\min}}$$

T_{s-max} = a + b*NDVI

T_{s-min} = a'+ b' *NDVI

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.

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.

TDVI 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. TDVI 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.

3.3 VWSI (Vegetation Supply Water Index)

VWSI (Vegetation Supply Water Index) is defined as follows:

$$VSWI=NDVI/T_s \quad (3)$$

Where NDVI= Normalized vegetation Index

T_s= Vegetation canopy temperature

The greater the VWSI, the more abundant the crop, and vice-versa. Under the normal water supply to maintain a certain range at a certain growth period, the vegetation canopy temperature follows a certain range. When experiencing drought, due to inadequate water supply, vegetation indices will reduce while vegetation canopy temperature rise. During drought, VSWI takes into account the effects of vegetation reflection on red, near infrared, thermal infrared band. This method is easy to realize and good for operability, very effective in the case where NDVI value is greater than 0.3.

4. THE ESTABLISHMENT AND IMPLEMENTATION OF DROUGHT MODEL

4.1 Introduction to Experiment

Based on the drought evaluation factors above, the paper establishes empirical drought model using statistical mode to enhance the applicability of methods and improve the accuracy of soil moisture, drought monitoring, combined with soil moisture data based upon actual ground measurements. Hubei province of China in late June 2008 was the experimental area to make detailed description of the model building process. In addition, the examples of Hubei in mid July 2008 and Hubei in late march 2009 were raised for supplement.

Hubei province affected by typical monsoon climate is located in subtropical zone. Besides the mountain region, the majority of the region had subtropical monsoon humid climate with abundant rainfall, which decreases from south to north. Drought in the spatial and temporal distribution has taken place in the four seasons, especially in the autumn.

The data in the model include remote sensing data and measured data in two parts. Remote sensing data with 1-km resolution is provided by MODIS (Moderate resolution Imaging Spectroradiometer) and measured data in the experiment from all the hydrological stations located in various parts of Hubei and Hubei provinces.

1.1 The establishment of a integrated drought index

The integrated model of drought is as follows:

$$DI=P_1XRSI+P_2XPI \quad (4)$$

Where *RSI*=Remote sensing Index

PI=Precipitation index

(P_1 P_2)= respectively weight coefficient

$P_1+P_2=1$

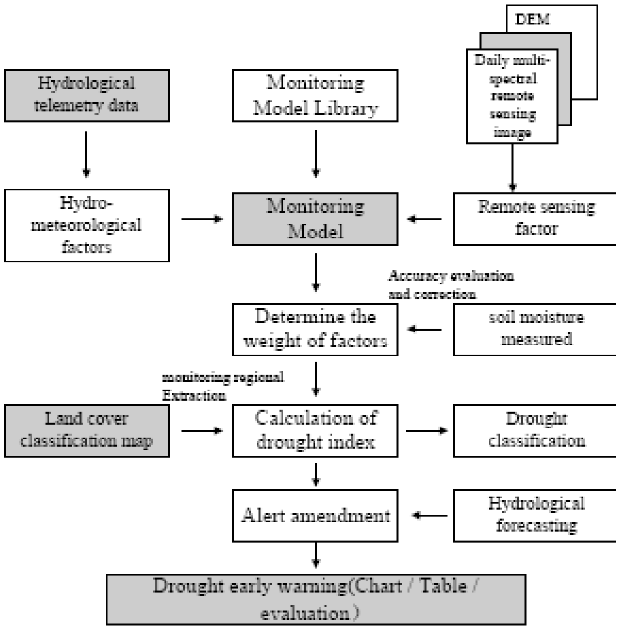

Figure 1. Flow Chart of Drought Early Warning Method

There are two problems to resolve for practical integrated model of the drought: 1) determining the contribution of parameters in the integrated model, right away determining the weight (P_i) of parameters. 2) Confirming the contribution significant of parameters in the integrated model. In order to determine contribution significant of TVDI, SPI in the integrated model, correlation coefficient of relative soil moisture and them needed to experience significant test. In this model, determination of each parameter weight has direct impact on the results. There are many methods to determine the weight, such as fixing the weight in the light of experience, or credibility of the data, or mathematical methods. If a parameter is strongly associated with relative soil moisture, the impact weight is also big, and vice versa. If the correlation among the various factors is very low, the correlation coefficient of factors and relative soil moisture is as reference weight to determine whether each factor has significant contribution to an integrated drought model and how much they contribute.

NDVI, LST, TVDI, VWSI, SPI and other drought evaluation factors are obtained from soil moisture stations of Hubei over ten days, and correlation of single factor and relative soil moisture is analyzed, detailed as follows:

$\|R\|$	VSWI	VTDI	SPI	DI
RSM	0.1439	0.5525	0.4974	0.6227

Table 1: Correlation of single index and RSM of Hubei in late June 2008 (RSM is respect for Relative Soil Moisture)

As can be seen from the table, correlation of TVDI and relative soil moisture is much higher than the one of VWSI and relative soil moisture so TVDI is chose as remote sensing index in this model. Soil moisture stations NDVIO of which is greater than 0.3 or very little analysis and it lead to that the correlation of VWSI and relative soil moisture is very low. In order to determine contribution significance of TVDI, SPI in the integrated model the correlation coefficient of relative soil moisture and single index needs to be tested for significance. When N=47, the degree of freedom: f=N-2=45. When α (reliability) = 0.001, its critical correlation coefficient: R_{α} =0.4648, correlation of TVDI and relative soil moisture:

$|R|$ =0.5525>0.4648 and correlation of SPI and relative soil moisture: $|R|$ =0.4974>0.4648. It shows that all the correlation of single index and relative soil moisture has achieved a very significant level, so they make a great contribution to the integrated model.

Preliminarily fixing the integrated model for the 10 days as follows:

$DI=P_1XTVDI+P_2XSPI$ ($P_1+P_2=1$)

When weight coefficient P_1 (P_2=1- P_1) value is from 0 to 1, circular correlation of DI (integrated drought index) and relative soil moisture in the step of 0.001, then statistic and compare the correlation coefficient to confirm the contribution significant of the parameters to integrated drought model, finally fix the weight of every parameters when P_1=0.54 (P_2=1- P_1=0.46), the correlation reach to maximum ($|R|$ =0.6227, in the table above). Finally the integrated model in the ten days is fixed as follows:

DI=0.54XTVDI+0.46XSPI

The correlation of the index composed by the indices and the relative soil moisture is significantly higher than the single index. It indicates that the combination of parameters will be better to reflect the actual situation, achieving the desired results.

4.3 Retrieve Relative Soil Moisture

Measured data is required to construct the model integrating remote sensing and rainfall information to fix the weight of factors and to verify the results and quantify levels of drought.

In order to retrieve the relative soil moisture, it is necessary to establish the statistical relationship model of RSM and DI. Then retrieve the RSM of each pixel, classifying the levels of drought according to standard for grading the degree of drought.

There are three common typical mathematical forms used in statistical modeling:

Linear model: $y=b_0+b_1X\,x$

Exponential model: y= $b_0+e^{\,b1X\,x}$

Logarithmic model: y= $b_0+b_1x\ln(x)$

Where, x and y are parameters representing the DI and the DI RSM, b_o, b_1 stand for the undetermined coefficients. Select the optimal model by comparing the different simulation accuracies. Under the same confidence level, the higher correlation coefficient of indicator is used to determine goodness of fit. The correlation coefficients of DI and the RSM in experimental zone and the fitting parameters of various statistical models are in Table 2.

equation	Statistics Model	correlation coefficient |R|	F	Ssize N
Linear form	RSM =1.1587-0.9474* DI	0.6227	28.493	47
exponential form	RSM =1.439*e - 1.545* DI	0.5968	24.888	47
logarithmic form	RSM=0.348-0.465*ln(DI)	0.6154	27.434	47

Table 2: Analysis Table of Statistical Model of Three Examples

According o look up table, know F0.01 (1, 45) +7.235. It is obvious that each statistical model in the table above has passed the significance level F test with reliability of 0.01. The correlation coefficient of linear from of model is better than other forms, so that linear model in his ten days is chosen.

Scatter plot of the liner model is shown in Figure 2:

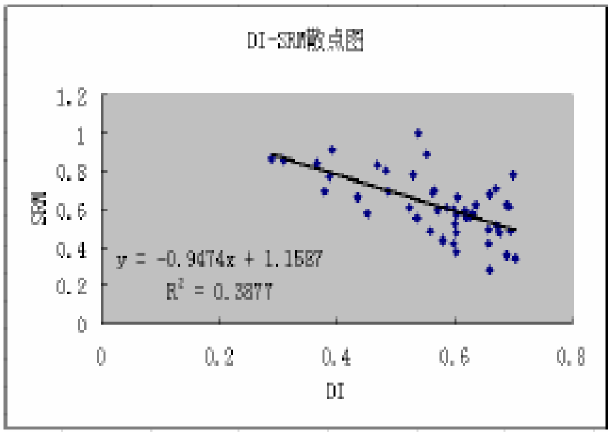

Figure 2. Scatter plot of DI and RSM in Late June 2008 of Hubei

4.4 Drought Classification

In this paper, standard for grading the degree of drought stated by China Meteorological Administration is adopted. The correspondence of RSM and drought levels are shown in table 3, divided in 5 grades.

drought levels	wet	normal	Light dry	Middle dry	Heavy drought
RSM	>0.8	0.6-0.8	0.5-0.6	0.4-0.5	<0.4

Table 3: Standard for Grading the Degree of Drought

Drought classification results are as follows:

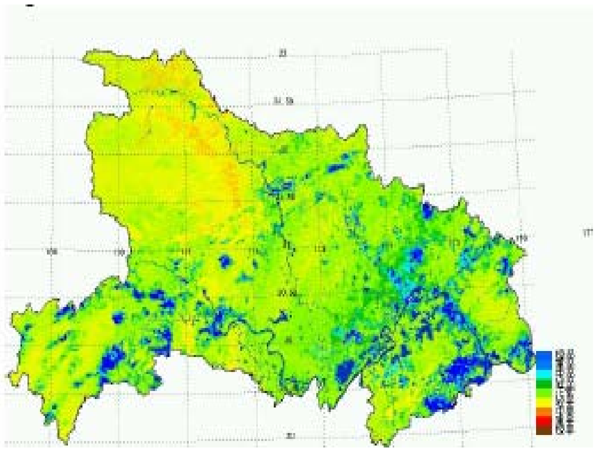

Figure 3. Drought Classification of Hubei in Late June 2008

The drought models and scatter plots are as follows by analysing the data from Hubei province in mid-July 2008 and late March 2009 by the same method as above.

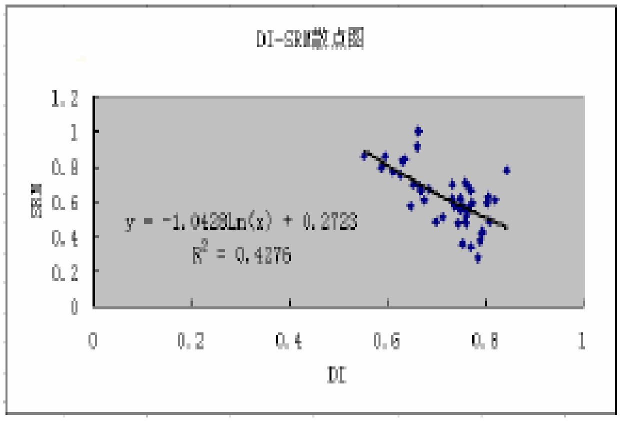

Figure 4. Scatter plot of DI and RSM in mid-July, 2008 of Hubei

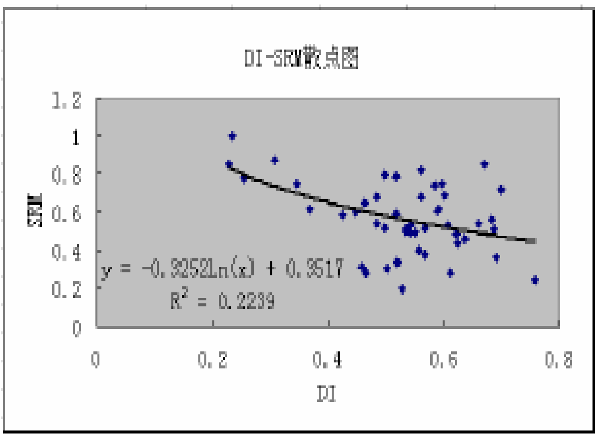

Figure 5. Scatter plot of DI and RSM in late March, 2009 of Hubei

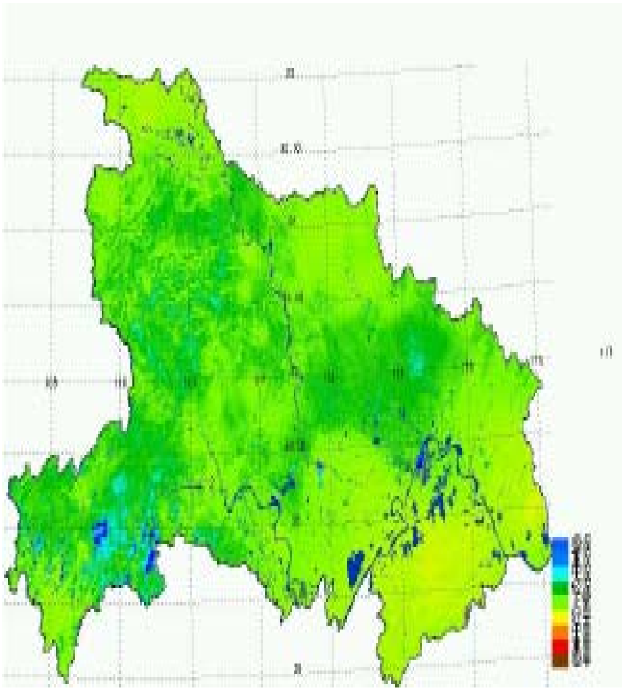

Figure 6. Drought Classification of Hubei in Mid July 2008

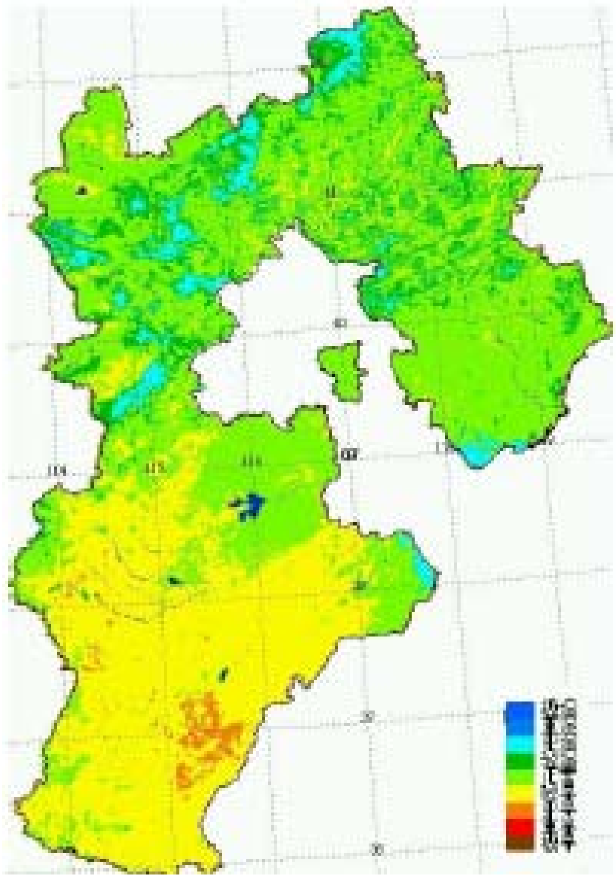

Figure 7. Drought Classification of Hubei in Late March 2009

5. ACCURACY ASSESSMENT AND ANALYSIS OF EXPERIMENTAL RESULTS

From the scatter plot of RSM and PRSM (predictive value of RSM) from Hubei in late June 2008, it is obvious that scatter points distribute nearly on both sides of a straight line and show a good linear distribution that indicating a good linear model.

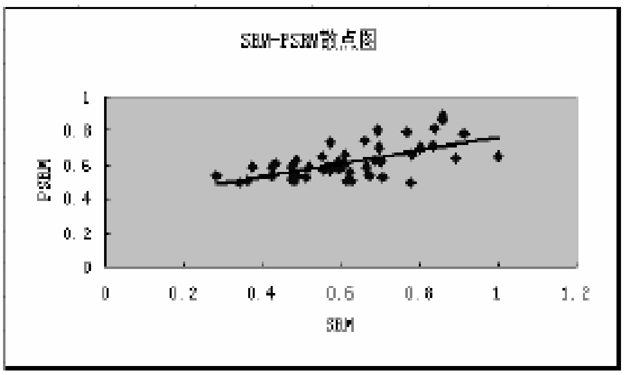

Figure 8. Scatter plot of RSM and PRSM in late June, 2008 of Hubei

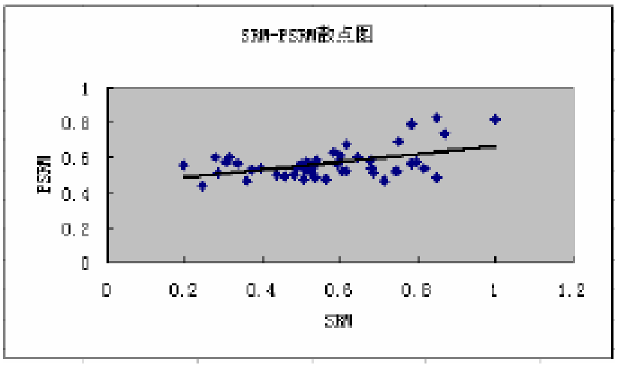

Figure 8. Scatter plot of RSM and PRSM in Mid July, 2008 of Hubei

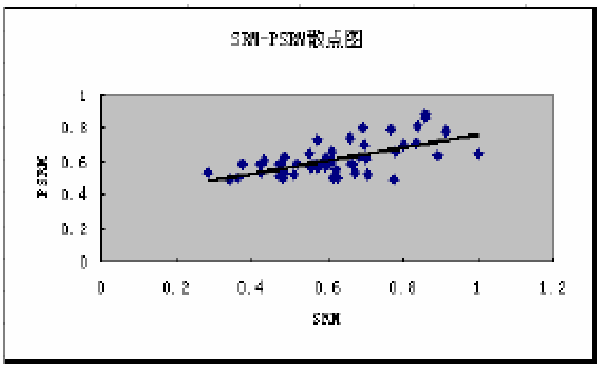

Figure 8. Scatter plot of RSM and PRSM in late March, 2009 of Hubei

With the comparison of RSM and PRSM, error analysis of the result was made. The average absolute error is 0.09711, while the average relative error is 0.17597. From a single station, the absolute error ranges from 0.00021 to 0.35137, the relative error mainly ranges from 0.00031 to 0.36156, relative error of few stations (5) ranges from 0.40543 to 0.89933.

As can be seen, the smaller the error of model inversion, better the fitting precision of the regression model. The formation and impact of the clouds bring big errors into image data at some stations.

At the same time, historical data show that the rainfall in most parts of the province during the ten days is less than normal, and spatial distribution of precipitation is uneven that in the south is less than in the north. It shows that RSM of 20 cm across the province has a general decline on June 28, except 90% for Yunxi. Zigui, Suizhou, Wuhan, Yicheng, Xiangyang, Gokseong are respectively only 60%, 61%, 62%, 66%, 67%, soil moisture is low, there are signs of drought; other sites have 70%~90%, soil moisture which is appropriate. Soil moisture of north-western parts of Hubei is low, as well as northern Jianghan Plain; light dry appeared in some areas.

There was abundant rainfall in Hubei Province in July 2008. Drought situation of some areas have reduced and RSM of all areas shows the area is suitable for the growth of crops. Due to the lack of effective rainfall in most areas of Hebei Province after March 2009, the drought of central and southern areas is serious. From the experimental results, detection is consistent with the reality.

In summary, drought monitoring results reflected by the integrated model for drought estimation are consistent with the actual situation, so it is feasible to use the method to monitor regional drought situation.

CONCLUSION

In the paper, study on drought monitoring by integrating remote sensing data and measured data from the mechanism of drought was studied. Choice of evaluation-factors for establishment of drought model were studied to achieve the simple, timely and accurate, drought monitoring. This can provide a new way for large-scale, real time, dynamic and automated early warning of drought by integrating remote sensing and no-remote sensing index. The next step will further improve the model, such as bring in other drought evaluation factors, to enhance the adaptability of the model, and improve accuracy by using more experimental data.

ACKNOWLEDGEMENT

The work presented in this paper is supported by National 948 project of China (2006110), which is named Hydraulic information service of grid system, aimed at introducing advanced foreign technology. Thanks for the leadership and colleagues in Water Information Center of the Ministry of Water Resources in China who provided the MODIS LIB data, thanks all the same to the leadership and colleagues in Beijing Golden-Water Info-Tech Ltd.

who supply the necessary experimental equipment and environment.

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