Technical Note

Soil Moisture Retrieval through Satellite Data for Gansu and Xinjiang Region of China

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Abstract

Soil moisture is an important agricultural, meteorological and hydrological parameter. Despite of its importance it is not easy to have the soil moisture observation continuously in large area. But it becomes possible to be monitored effectively and conveniently by remote sensing. Observed soil moisture data and MODIS data of MOD11A2 and MOD13A2, for the months of May, July and October (2007-2010) were used. GanSu Province and XinJiang Uygur Autonomous Region in China were chosen as a study area. Temperature Vegetation Dryness Index (TVDI) was derived using Normalized Difference Vegetation Index (NDVI) product MOD13A2 and Land Surface Temperature (LST) product MOD11A2. TVDI was incorporated in equation so as to derive relative soil moisture. In this study soil moisture data of 98 stations, of 10 cm depth were used. 75 stations were used to simulate the model and data of 23 stations were used for validation/comparison of results. Average relative error in simulated soil moisture is 29. 43 %.

Introduction

Soil moisture plays an important role in agriculture and environmental characteristics of a region. It influences surface water balance and energy exchange between land and atmosphere (Song, 2000). Available soil water contents along with the sunlight are used by the plants during the growth process. It is also released to the atmosphere by the process of evapotranspiration. Vegetation cover and the soil moisture contents affect the surface radiant temperature.

Soil moisture is very important in agricultural point of view, in drought analysis and flood forecasting. Surface soil moisture can also influence the interaction between land and atmosphere(Koster, 2004). For most of the hydrological models soil moisture is a mandatory input.

Despite the importance of soil moisture, the in situ measurement is very difficult and requires resources, both human and financial. Only limited area can be covered by in situ point observation, which cannot be the representative of the wide region.

Satellite remote sensing can be a good alternate for the estimations of soil moisture values, because of its spatial coverage and temporal continuity. With the technological advancement in remote sensing through satellite data, different techniques have been developed for the measurement of soil moisture across a wide area at different time scale (Engman, 1990).It also cost effective means for estimating soil moisture at a large scale.

Normalized Difference Vegetation Index (NDVI) highly correlates with water stress and rainfall ((Liu & Kogan, 1996).The NDVI value also depends upon the type of soil, for dark soil the values are larger and for light colored soil the NDVI values are smaller (Nicholson & Farrar, 1994). Land surface Temperature (LST) and NDVI can be used to estimate soil moisture, by incorporating Soil Vegetation Atmosphere Transfer (SVAT) model (Carlson, 2007). The data scarcity of soil moisture affects the agriculture and environment badly. If sufficient amount of moisture is not available to the crops for a long period, the outcome will be the agricultural drought. As the NDVI is sensitive to water stress, it can also be used as a good indicator in monitoring drought (Liu & Ferreira, 1991).

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Study Area

In this study the focus area is Gansu province and XinJiang region of Peoples Republic of China. Gansu Province is located in the upper Yellow River, with a total land area of 454,400 square kilometers. It is located at latitude 32 ° 11 ' ~ 42 ° 57 ' and longitude 92 ° 13 ' ~ 108 ° 46 ', with most located on the two steps of the terrain. (Figure 1)

Complex and diverse landforms include mountains, plateaus, plains, valleys, deserts. The terrain slopes from southwest to northeast and the terrain is long and narrow, 1655 km from east to west, 530 km from north to south. The Yellow River flows through Gansu Province, and the basin covers most of the loess areas. This area is characterized by sparse vegetation, soil erosion and river sedimentation. From southeast to northwest, Gansu has various climate types, including the north subtropical humid zone to the high cold zone.

Xinjiang Region is located in Central Eurasia, in the northwest border of China, with a total area of 1,664,900 square kilometers. Xinjiang Region is the China's largest provincial-level administrative regions. It is located between 73 ° 40 ' E ~ 96 ° 18 ' E and 34 ° 25 ' N ~ 48 ° 10 ' N.

The terrain in Xinjiang is alternately the mountains and basins. Altay is located in northern Xinjiang, Kunlun Mountain and Tianshan Mountain is located in south, forming the southern and northern Tarim Basin and Junggar Basin. The average annual precipitation is 150 mm, but varied widely. In general, winter temperatures in northern part are higher than southern, however, in summer the situation is opposite. The coldest month (January), the average temperature is minus 20 ° C. The hottest month (July), the absolute maximum temperature was up to 49.6 ° C. In most parts of Xinjiang region the daily temperature varies greatly in every season.

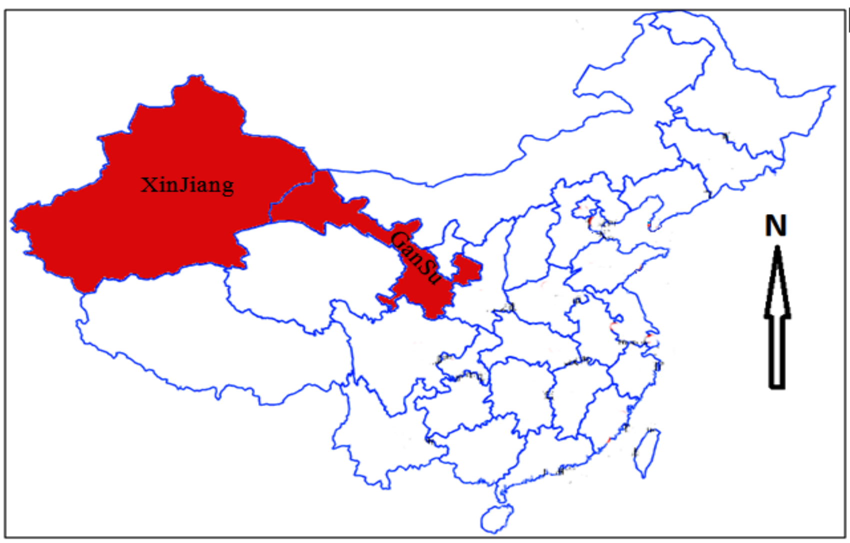

Figure 1: Location map of GanSu province and XinJiang region.

Data and Methodology

NDVI and LST both depends upon the soil moisture content in a complex way. Carlson et al., 1994 and Gillies&Carlson., 1995 demonstrate the relationship between these two variables and the soil moisture. When the scattered plot of scaled NDVI and LST is plotted in which LST abscissa and NDVI is the ordinate, the shape of the graph resembles the triangle (Figure 2)

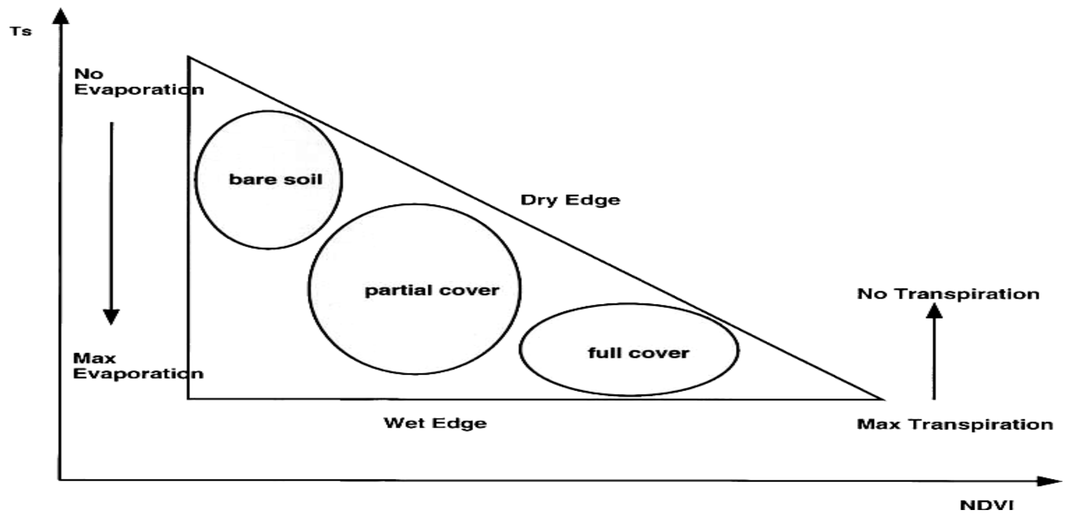

Figure 2: Triangular relationship between Soil Moisture, LST and NDVI (Sandholt, 2002)

In the triangle the variation of soil moisture is from right to left. Right side represents high soil moisture content while at the left side the soil moisture is low. With the increase in NDVI values there is a decrease in the LST. At the top edge of the triangle the vegetation is at the maximum and the corresponding value of temperature is low with very little variation. The variation in temperature with high NDVI values is due to the variation in soil moisture (Carlson, 2007). The point where the soil moisture content is higher the temperature will be low as compare to the dry point, although the NDVI value is the same.

In this study two MODIS Products MOD11A2 (Land Surface Temperature) and MOD13A2 (NDVI) was used to calculate Temperature Vegetation Dryness Index (TVDI). TVDI was correlated to observed soil moisture.Three months (May, July and October) were selected as representative of three seasons (spring, summer and autumn) receptively. In winter season, most of the time soil remain frozen, in most parts of the study area and soil moisture observations were not taken.

TVDI is expressed as

$$TVDI = \frac{T_s - T_{s\min}}{T_{s\max} - T_{s\min}} \tag{1}$$

Where T_{smin} and T_{smax} are the minimum and maximum temperature respectively.

$$T_{s\max} = a + bNDVI \tag{2}$$

And

$$T_{s\min} = a' + b'NDVI \tag{3}$$

Where a, b, a' and b' are the coefficient of regression lines of warm edge (Dry line) and cold edge (moist line)

Relative Soil Moisture (RSM) can be related to theTsmin and Tsmax with the following equation:

$$\frac{RSM_w - RSM}{RSM_w - RSM_d} = \frac{T_s - T_{s\min}}{T_{s\max} - T_{s\min}} \tag{4}$$

From equation (4) relative Soil Moisture content can be found as:

$$RSM = RSM_w - \frac{T_s - T_{s\min}}{T_{s\max} - T_{s\max}} \left(RSM_w - RSM_d \right) \tag{5}$$

$$RSM = RSM_w - TVDI \times \left(RSM_w - RSM_d \right) \tag{6}$$

Where RSMw is the completely wet soil with value 100. So equation (6) can be written as:

$$RSM = 100 - TVDI \times (100 - RSM_d) \tag{7}$$

Dry and wet edge of the triangle is determined after extracting the Tsmin and Tsmax. The positive value of NDVI from 0 to 1 is divided into 100 parts ie{0.01, 0.02, 0.03……1}. For each of the individual value of scaled NDVI, both Tsmin and Tsmaxis determined. Once we get the T_{smin} and T_{smax} these two variables are plotted along with NDVI. The trend line of Tsmax gives the dry edge and that of the Tsmin represents wet edge. Equation of dry edge is incorporated in Eqn (7) for RSMd. All the equations and corresponding R^2 values are shown in Table-1.

Table 1: Equations of dry edge, wet edge and R^2 values for T_s-NDVI space (2007-2010)

S.No.	Date	Equation of Dry Edge	R^2	Equation of Wet Edge	R^2
1	09/05/2007	T_{smax}=-28.12NDVI+53.05	0.81	T_{smin}=17.53NDVI-6.25	0.82
2	25/05/2007	T_{smax}=-31.36NDVI+55.80	0.85	T_{smin}=19.30NDVI - 5.80	0.76
3	12/07/2007	T_{smax}=-31.30NDVI+64.30	0.91	T_{smin}=17.84NDVI-4.37	0.71
4	28/07/2007	T_{smax}=-33.05NDVI+64.81	0.87	T_{smin}=22.08NDVI-3.90	0.68
5	16/10/2007	T_{smax}=-25.84NDVI+36.92	0.95	T_{smin}=12.56NDVI-13.47	0.24
6	08/05/2008	T_{smax}=-37.66NDVI+61.58	0.95	T_{smin}=19.81NDVI-2.48	0.67
7	24/05/2008	T_{smax}=-36.83NDVI+63.32	0.92	T_{smin}=24.98NDVI-9.78	0.87
8	11/07/2008	T_{smax}=-37.30NDVI+67.53	0.92	T_{smin}=21.66NDVI-2.86	0.74
9	27/07/2008	T_{smax}=-36.18NDVI+65.56	0.92	T_{smin}=19.54NDVI-3.02	0.88
10	15/10/2008	T_{smax}=-23.49NDVI+38.37	0.95	T_{smin}=13.26NDVI-4.97	0.80
11	31/10/2008	T_{smax}=-19.68NDVI+29.21	0.96	T_{smin}=20.91NDVI-12.35	0.72
12	09/05/2009	T_{smax}=-35.07NDVI+54.41	0.88	T_{smin}=20.03NDVI-8.78	0.69
13	25/05/2009	T_{smax}=-35.20NDVI+56.40	0.93	T_{smin}=22.47NDVI-11.04	0.84
14	12/07/2009	T_{smax}=-35.85NDVI+64.48	0.89	T_{smin}=14.93NDVI-5.63	0.56
15	28/07/2009	T_{smax}=-34.81NDVI+63.69	0.88	T_{smin}=19.77NDVI-4.52	0.73
16	16/10/2009	T_{smax}=-25.27NDVI+38.08	0.95	T_{smin}=12.37NDVI-7.26	0.45
17	09/05/2010	T_{sma}x=-34.41NDVI+54.28	0.95	T_{smin}=15.54NDVI-7.51	0.46
18	25/05/2010	T_{smax}=-22.40NDVI+56.91	0.81	T_{smin}=14.0NDVI-11.18	0.57
19	12/07/2010	T_{smax}=-36.20NDVI+65.54	0.92	T_{smin}=17.07NDVI-5.72	0.58
20	28/07/2010	T_{smax}=-28.86NDVI+59.10	0.92	T_{smin}=25.08NDVI-7.28	0.89
21	16/10/2010	T_{smax}=-23.95NDVI+38.16	0.96	T_{smin}=14NDVI-7.14	0.78

R^2 values are significant at 95% confidence interval.

Soil moisture data of 10 cm depth of 98 stations were used. The data was split into two parts 75 stations data was used to develop the model for estimation of soil moisture at unknown locations, while 23 stations data was used to validate the model prediction result. Table-2 shows the results.

Results and Discussions

Table 2 shows the values of actual and simulated soil moisture. It is clear that differences exist between actual and simulated soil moistures, which further intensify when the actual soil moisture is high. At low soil moisture the difference is comparatively less.

Table 2: Date wise comparison of actual soil moisture, simulated soil moisture and relative error.

Date	Actual SM（%）	Simulated soil moisture（%）	Relative Error （%）
09/05/2007	53.87	42.95	20.28
25/05/2007	63.04	39.49	37.36
12/07/2007	80.09	50.75	36.64
28/07/2007	81.74	52.18	36.16
16/10/2007	87.38	49.80	37.25
08/05/2008	57.79	43.44	24.84
24/05/2008	52.71	42.09	20.15
11/07/2008	60.92	47.14	22.62
27/07/2008	52.20	47.06	9.85
15/10/2008	73.96	47.69	35.52
31/10/2008	73.82	46.31	37.26
09/05/2009	50.63	36.81	27.29
25/05/2009	62.64	44.63	28.75
12/07/2009	57.21	38.58	32.56
28/07/2009	61.13	44.06	27.93
16/10/2009	69.88	43.84	37.27
09/05/2010	51.56	34.85	32.41
25/05/2010	67.95	49.20	27.60
12/07/2010	56.07	43.94	21.63
28/07/2010	64.22	44.02	31.45
16/10/2010	65.61	43.83	33.19
Average	64.020	44.412	29.43

Relative errors were also dependent on the value of actual soil moisture. Increase in actual soil moisture causes increase in relative error. In case of abrupt increase in actual soil moisture; the corresponding error in simulated soil moisture also increases. For example on 2007-07-28 and 2007-10-16, values of actual soil moistures were 81.74% and 87.38% respectively. On these two particular dates the relative errors in simulated soil moistures were 36.16% and 37.25 %. This increase is possible in case of heavy precipitation or due to irrigation. Whatever the reason of increase may be, NDVI cannot respond so quickly to the increase in soil moisture due to natural lag, hence relative error is high. Over all the average relative error in simulated soil moisture were 29. 43 %.

When there was a sharp or sudden increase in the observed soil moisture due to precipitation or irrigation, the model fails to catch that type of variations. The reason is that the change in the status of vegetation or water content of vegetation is not simultaneous with that of soil moisture. The vegetation can survive for considerable time if the soil moisture supply is suddenly stopped. Similarly if the availability of soil moisture is increased by some way, the response of the vegetation will be slow.

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