韓國水資源學會論文集
第31卷 第2號 · 1998年 4月
pp. 145 ~ 153

Washita '92 토양수분 자료의 1차원 및 2차원 통계특성

First- and Second-Order Statistics of Washita'92 Soil Moisture Data

유 철 상* / 신 사 철**

Yoo, Chulsang / Shin, Shachul

Abstract

In this paper the first- and second-order statistics of soil moisture are derived using the Washita '92 data. Also the possible correlations among the soil texture, the brightness temperature, the NDVI and the soil moisture are investigated based in the linear regression study. Only the correlation between the soil moisture and the brightness temperature shows significant values. The soil moisture decay coefficients in time were estimated for each soil type and cross-checked by calculating the last rainfall time before the observation to be about 20 days in all different soil types. The second order statistics of soil moisture based on the correlogram and the spectrum was analyzed to derive the data characteristics and compared with those of the NDVI and the soil texture. This analysis shows that the soil moisture within the highly correlated soil texture field is affected much by the relatively less correlated vegetation field in the Washita area, where the effect of topography is known to be small. The soil moisture dynamics model based on the linear reservoir concept and considering the diffusion through the soil media was derived and its parameters were estimated successfully using the first- and second-order statistics.

Keywords : soil moisture, soil moisture model, correlogram, spectrum

요 지

이 논문에서는 Washita '92 자료를 이용하여 토양수분의 1차원 및 2차원 통계특성을 추출하였다. 아울러, 토양수분과 토양, 밝기온도(brightness temperature), 식생지수 사이의 상관관계가 어떤지를 선형회귀분석에 근거하여 조사해 보았으며 결과로서 토양수분은 밝기온도와 유의할만한 상관성이 있는 것으로 나타났다. 토양수분의 시간에 대한 감쇠(decay)계수를 각각의 토양군별로 추정하였고, 역으로 이 값을 이용하여 관측전 마지막 강우의 시점을 추정해 본 결과 관측기록과 유사한 20일 정도로 나타났다. 토양수분의 2차원 통계특성 분석은 2차원 상관도와 스펙트럼을 도출하고 분석함으로서 수행하였으며 토양과 식생지수에 대한 2차원 분석결과와 비교하였다. 이러한 분석 결과로 토양수분은 공간적으로 매우 높은 상관성을 갖는 토양과 상대적으로 낮은 상관성을 보이는 식생의 공간적인 2차원 통계특성을 나타냄을 알 수 있었다. 즉, 지형이 완만하여 지형적인 영향이 상대적으로 적다고 알려진 Washita지역의 경우 공간적으로 높은 상관성을 보이는 토양의 공간에 존재하는 토양수분은 상대적으로 낮은 상관성을 보이는 식생에 의해 교란되고 있음을 파악할 수 있었다. 선형저수지의 개념과 공간적인 확산을 고려한 동역학적 토양수분 모형의 유도과정을 보였고 모형의 매개변수가 토양수분의 1차원 및 2차원 통계특성으로부터 효과적으로 추정될 수 있음을 보였다.

핵심용어 : 토양수분, 토양수분모형, 상관도, 스펙트럼

* 고려대학교 자연과학대학 환경공학과 조교수
** 안동대학교 공과대학 토목환경공학과 전임강사

1. Introduction

Soil is a thin layer of porous material between the atmosphere and the geosphere. The retention of soil moisture and the attendant runoff from naturally occurring rainfall, snowmelt, or irrigation are fundamental processes upon which civilization depends for food production, portable water, and navigable streams and waterways. Soil moisture is also the dominant factor in shaping the ecosystem response to the physical environment. Adequate knowledge of soil moisture storage as well as evaporation and transpiration at the land surface is essential to the understanding and prediction of the reciprocal influences between land surface processes and weather and climate. Despite the importance, global measurement and analysis of soil moisture and temperature remains deficient.

Traditionally, hydrologists have had to practice without adequate knowledge of the three dimensional distribution of soil moisture and its variation in time. Ground-based methods for observing soil moisture, such as the gravimetric techniques, neutron probes, time domain reflectometry, etc., are generally labor intensive. Except for selected sites of agricultural concern and certain research watersheds, the data necessary to construct a soil climate (e.g., soil temperature, soil moisture, etc.) is conspicuously missing, particularly when comparing with the notion of atmospheric climate. The spatially distributed and physically based water balance models introduced in the past two decades have certainly been hampered by the lack of data adequate for prognostic and diagnostic purposes.

Remote sensing of surface soil moisture at microwave frequencies will no doubt contribute significantly to the investigation of soil moisture distribution and dynamics. Currently several projects for large or global scale soil moisture observation are on planning by the U. S. and European Community. The success of these projects, however, depends on the quality of the basic statistics, especially the second order moment, and the model for soil moisture dynamics, which will, in turn, be tuned by the data collected (North and Nakamoto, 1989). Modeling efforts given to the soil moisture can be found in Rodriguez-Iturbe et al. (1991), Entekhabi and Rodriguez-Iturbe (1994), etc., but their aims were to see the effect of rainfall on the soil moisture spatially and temporally. It's also worthwhile to notice that they have used a very conceptive and typical values for the model parameter, not the observed.

In this study, the first and second-order statistical characteristics of the soil moisture field based on the Washita '92 data analysis are investigated. This study may be extended toward understanding the physical characteristics of the soil moisture and the spatial organization of it. The statistics derived, then, are applied for the parameter estimation of a simple soil moisture dynamics model.

2. Washita '92 Data

Washita '92 was a cooperative experiment between NASA, USDA, several other government agencies, and universities with the primary goal of collecting a time series of spatially distributed data focusing on soil moisture and evaporative fluxes (Jackson et al., 1993). Data collection was conducted from June 10-18, 1992. The region received heavy rains over a period before the experiment started, with the rain ending on June 2, and no precipitation occurred during the experiment period. The ESTAR (Electronically Scanned Thinned Array Radiometer) and many other operational sensors were carried by a NASA aircraft. Besides the ESTAR passive microwave data and the soil moisture data, it provides the information on soil texture and land use that would be relevant for further research. All the image files are 228 pixels by 93 lines covering an area of 45.6 km×18.6 km (846 km^2) with pixels of 200 m×200 m. This area is located in southwest Oklahoma, and belongs to the Little Washita watershed and has a channel system which provides adequate drainage.

Table 3. Regression Analysis for the Soil Moisture (SM) and the Brightness Temperature (BT) with the NDVI of the Washita '92 data

Regression	Soil Type (Porosity)	a	b	R^2	Comments
(1) SM = a(NDVI) + b	I (0.417)	-0.0057	16.52	0.0014	Corr(porosity, a) = -0.2621
	II (0.401)	-0.0109	20.19	0.0031	
	III (0.412)	-0.0183	21.38	0.0102	
	IV (0.434)	-0.0264	28.15	0.0212	
	V (0.486)	-0.0383	29.48	0.0379	
	VI (0.437)	0.0623	28.75	0.0404	
(2) BT = a(NDVI) + b	I (0.417)	0.0711	300.84	0.030	Corr(porosity, a) = 0.0654
	II (0.401)	0.1373	287.46	0.069	
	III (0.412)	0.1428	288.03	0.068	
	IV (0.434)	0.0814	277.44	0.033	
	V (0.486)	0.1146	275.35	0.056	
	VI (0.437)	-0.1905	289.14	0.096	
Corr($a_{(1)}$,$a_{(2)}$) = -0.9273					

Table 4. Decay Coefficients of Soil Moisture (SM) and Brightness Temperature (BT) for Different Soil Texture

Soil Type (porosity)	Soil Moisture α(STDV)	Brightness Temperature α(STDV)	Time after Rain (day)
I (0.417)	0.092 (0.035)	-0.012 (0.0051)	19.57
II (0.401)	0.072 (0.027)	-0.013 (0.0058)	22.22
III (0.412)	0.076 (0.033)	0.099 (0.0378)	20.3
IV (0.434)	0.057 (0.027)	-0.014 (0.0063)	22.24
V (0.486)	0.062 (0.036)	0.015 (0.0075)	19.7
VI (0.437)	0.081 (0.033)	-0.019 (0.0064)	15
Corr(porosity, α_{SM}) = 0.4851 Corr(porosity, α_{BT}) = -0.2797 Corr(α_{SM}, α_{BT}) = 0.0926			

(3) Two-dimensional spectrum derivation using inverse Fourier Transform of the periodogram.

This procedure was applied for the soil moisture, the soil texture, and the NDVI of Washita '92 data. The resulting correlograms and the spectra are given in Figures (1) and (2).

As shown in Figures (1), the two-dimensional correlograms are smoothly decayed to zero as the distance increases. The decay rate is highest for the soil texture and lowest for the NDVI. The soil moisture field has the decay rate in between the soil texture and the NDVI. The lag-1 correlation coefficient for the soil texture is highest among three data and the lowest for the NDVI. This indicates that the soil moisture within the highly correlated soil top layer is a little disturbed by relatively less correlated vegetation field in space. It is also obvious that the soil moisture field is affected by the topography, but for the Washita area the landscape might be assumed flat to disregard the effect of it. The spectrum also showed similar patterns.

The spectrum is centered at zero and smoothly decays to zero as the frequency increases. The relative magnitude of the peak at the center of the spectrum is biggest for the soil texture and least for the NDVI. The peak of the soil moisture field is in between the soil texture and the NDVI. This directly means that the variability of the soil moisture field is a little higher than that of the soil texture field, but both are less than that of the vegetation field. This coincides with the result

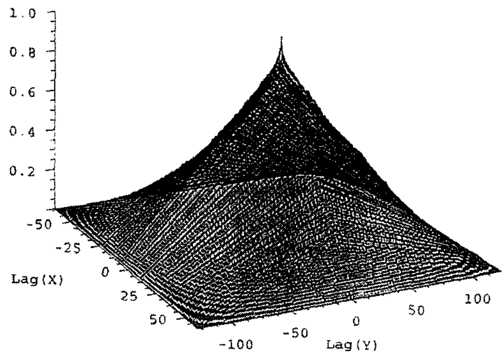

Figure 1(a). Two-Dimensional Correlogram of Washita '92 Data - Soil Moisture

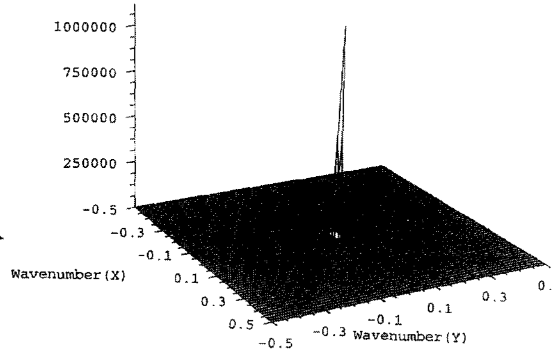

Figure 2(a). Two-Dimensional Spectrum of Washita '92 Data - Soil Moisture

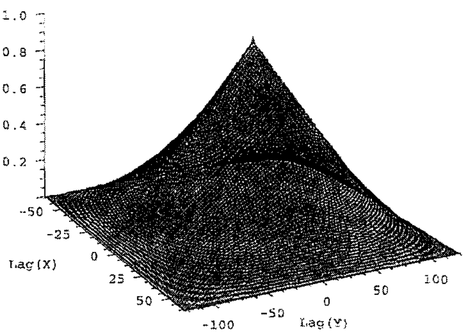

Figure 1(b). Two-Dimensional Correlogram of Washita '92 Data-Soil Texture

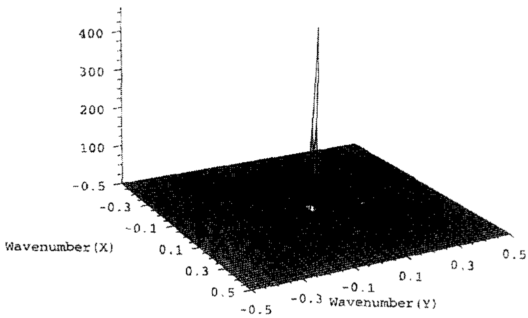

Figure 2(b). Two-Dimensional Spectrum of Washita '92 Data - Soil Texture

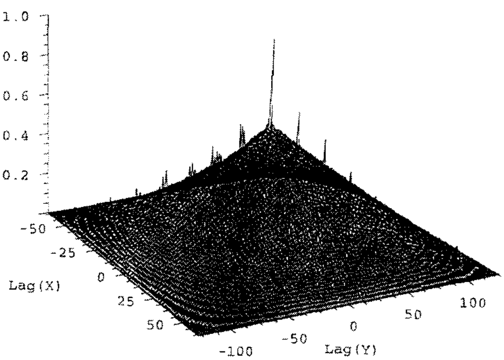

Figure 1(c). Two-Dimensional Correlogram of Washita '92 Data - NDVI

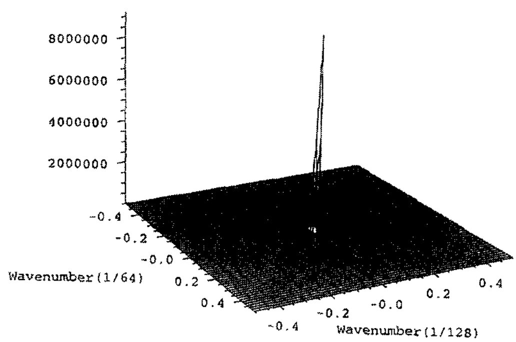

Figure 2(c). Two-Dimensional Spectrum of Washita '92 Data - NDVI

and control. Prentice-Hall, London.

Entekhabi, D. and Rodriguez-Iturbe, I. (1994). "Analytical framework for the characterization of the space-time variability of soil moisture." *Advances in Water Resources*, Vol. 17, pp. 35-45.

Jackson, T.J., Engman, E.T. and Schiebe, F.R. (1993). "Washita '92 experiment description." *Hydrology data report*, Edited by Jackson, T.J. and Schiebe, F.R., National Agricultural Water Quality Laboratory, 93(1).

North, G.R. and Nakamoto, S. (1989). "Formalism for comparing rain estimation designs." *J. Atmos. Ocean. Tech.*, Vol. 6, pp. 985-992.

Polyak, I. and North, G.R. (1995). "The second-moment climatology of the GATE rain rate data." *Bulletin of the American Meteorological Society*, Vol. 76, No. 4, pp. 535-550.

Rodriguez-Iturbe, I., Entekhabi, D. and Bras, R.L. (1991). "Nonlinear dynamics of soil moisture at climate scales: 1. Stochastic analysis." *Water Resour. Res.*, Vol. 27, No. 8, pp. 1899-1906.

Rodriguez-Iturbe, I., Vogel, G.K., Rigon, R., Entekhabi, D., Castelli, F. and Rinaldo, A. (1995). "On the spatial organization of soil moisture field." *Geophysical Research Review*, Vol. 22, No. 20, pp. 2757-2760.

Yoo, C., Valdes, J.B. and North, G.R. (1998). "Evaluation of the impact of rainfall to the soil moisture variability." *Advances in Water Resources*, Vol. 21, No. 5, pp. 375-384.

<최종본 접수일 : 1998년 1월 22일>