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"Time Stability of Field Observations of Soil Water Contents"

M. VAUCLIN
Institut de Mécanique de Grenoble
C.N.R.S.
Saint Martin d'Hères
France

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P. Udluft · B. Merkel · K.-H. Prösl

Department of Hydrogeology and Hydrochemistry,
Technical University of Munich, FRG

TIME STABILITY OF FIELD OBSERVATIONS OF SOIL WATER CONTENTS

Vauclin, Michel, Vachaud, G. & Passerat de Silans, A.

M.Vauclin, G.Vachaud und A.Passerat de Silans,
Institut Mecanique de Grenoble, LA CNRS n° 6, BP 68,
38402 Saint Martin d'Heres Cedex, France

ABSTRACT

Soil water data collected from two different fields are analysed in order to search if time-invariant characteristic statistical properties of the probability density functions can be assigned to individual locations. A grass field was equipped with 17 neutron access tubes and surveyed twenty four times during a 2 ½ year-period. In another field, planted with olive trees, 9 neutron access tubes were installed and quarterly measurements were performed during two consecutive years.

All the results converge to show the existence of a very significant time-stability of particular individual locations which are characterized by the same parameter in the statistical distribution of the observations taken over the field. It is shown that some locations conserve the property to represent the mean and extreme values of the field water content at any time in the year. This stability seems to be explained to a large extent by relationships between soil texture and water content.

INTRODUCTION

A strong objection commonly voiced by research engineers and technicians regarding the development of a field sampling strategy is the requirement of a large number of observations due to the spatial variability of soil properties [1,2].

Hence, a high research priority is the development of a methodology that reduces the number of observations without any significant loss of information .

This paper describes a tentative method to assess the representativity of individual sites in a large network of soil water content measurements.

DEVELOPMENT OF THE METHOD

The method depends upon the following conditions to be satisfied :

i) - At a given time t, sufficient field observations of any variable of interest are available to determine their probability density function (pdf) and its associated first moments (mean and variance).

ii) - Because the location of each observation is known, the spatial structure (i.e. distance of autocorrelation, stationarity, isotropy) can be identified.

iii) - A statistical representativity is assigned to each location.

The proposed method deals with the reliability of a particular location to continue, at other sampling times, to exhibit the same statistical representativity in the distribution of observations taken over the entire field. We will define this time invariant association between spatial location and statistical description, if it does exist, as the concept of time stability. For instance, in terms of the soil moisture status, this concept is realistic, because it is well know that the spatial variability of soil water content over a field can be explained in large extent by the variability of soil texture. There may be a high probability that if a location is the wettest at a particular time of measurement, it will remain the wettest at other times because of its highest clay content for instance.

In order to evaluate this time stability concept, two techniques are used.

1) - The first one concerns the deviation $\Delta_{i,j}$ between an individual observation of any variable of interest $X_{i,j}$ at location i (i=i,I) and at time j(j=1,J) and the mean value $\overline{X}_j$ at the same time :

$$\Delta_{i,j} = X_{i,j} - \overline{X}_j \tag{1}$$

with : $\overline{X}_j = \frac{1}{I} \cdot \sum_{i=1}^{I} X_{i,j}$

$\Delta_{i,j}$ can also be normalized as :

$$\delta_{i,j} = \Delta_{i,j} / \overline{X}_j \tag{2}$$

in order to obtain relative deviations.

Hence for any location i, the time average $\overline{\delta}_i$ and the temporal standard deviation $\sigma(\delta_i)$ can be straightforwardly calculated for the whole time series of observations. Ranking the $\overline{\delta}_i$ values from the smallest to the largest ones allows to identify locations which systematically either overestimate ($\overline{\delta}_i > 0$) or underestimate ($\overline{\delta}_i < 0$) the average regardless of the observation time. It is also possible to select an individual site which provides informations close to the field average ($\overline{\delta}_i = 0$) and to judge how the time stability concept is warranted by analysing the temporal standard deviations for any site.

2) - The second technique is based on the non-parametric Spearman's test. Let $R_{i,j}$ be the rank of the variable $X_{i,j}$ and $R_{i,j'}$, the rank of the same variable at the same location, but on time j'. The Spearman rank correlation coefficient is calculated by :

$$r_s = 1 - \frac{6 \sum_{i=1}^{I} (R_{i,j} - R_{i,j'})^2}{I(I^2-1)} \tag{3}$$

A value $r_s = 1$ will correspond to identical rank for any site or perfect time stability between times j and j'. The closer to 1 r_s is the more stable the process will be.

RESULTS

This concept of time stability as previously defined has been tested on a 2000 m^2 grass field located on the campus of the University of

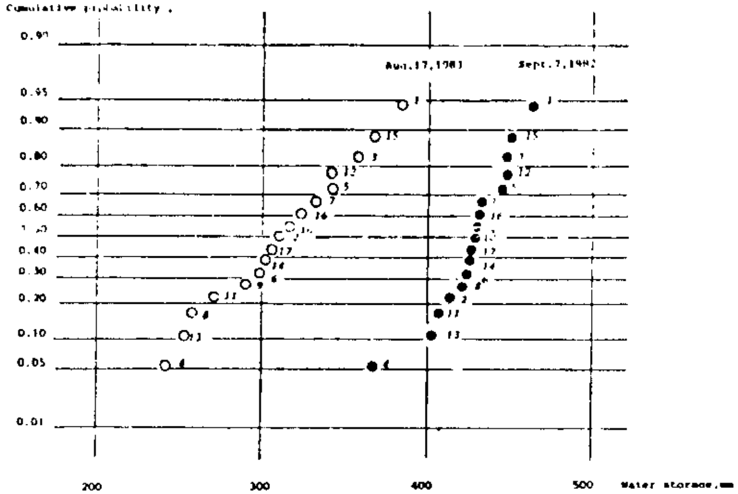

Fig. 1 - Site of Grenoble. Cumulative probability density functions of soil water storage in the first meter measured in the dryest, and the wettest situation. Numbers refer to locations of measurements (see Vauclin et al., 1984).

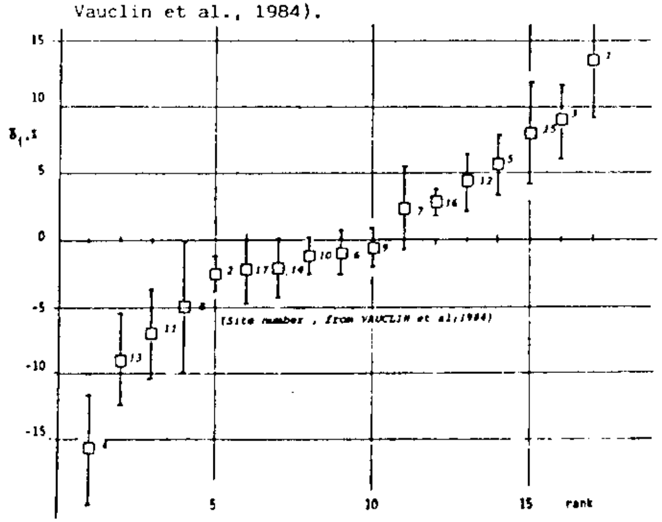

Fig. 2 - Site of Grenoble. Ranked intertemporal relative deviation from the mean spatial water storage. Vertical bars correspond to associated time standard deviation. Same symbolism as in Fig. 1.

Grenoble. This site, previously described in details [3] together with its instrumentation was equipped with 17 neutron access tubes installed at an isometric interval of 10 m. The soils is an alluvional deposit, with lenses of sand in a silty clay material at a depth below 50 cm.

A neutron moisture meter was used to measure soil water content every 10 cm to a depth of 100 cm along each access tube. Data were taken during 2 ½ years (from May 1981 to November 1983). Measurements were made once every two weeks during each summer and fall and bimonthly during winter and spring.

At each location i, a total of 24 sets of measurements were made and soil water storage $S_{i,j}$ held in the first meter was computed by the Simpson'rule of integration.

At each time of measurement, the water storage values were found to be randomly and normally distributed [3]. As an example Fig. 1 gives the cumulative probability function of S_i in two extreme situations : the wettest on September 7, 1982 (S_j = 429 $\pm$ 23 mm) and the dryest on August 17, 1983 ($\bar{S}_j$ = 313 $\pm$ 40 mm).

It should be mentioned that uncertainties associated with each individual estimation of water storage (approximately $\pm$ 5 mm) [4] are significantly smaller than the standard deviation related with spatial variations.

Fig. 2 gives the ranked $\bar{\delta}_i$ values calculated according to Eqs 1 and 2 with $X_{i,j} = S_{i,j}$. For instance, the water storage in location 4 is always 15.7 $\pm$ 4,3 % smaller the field average ; whereas that in location 1 is 13.4 $\pm$ 4.4 % greater. Of particular interest is the fact that in three locations (6,9 and 10) the water storage is never significantly different from the field average value. Notice also that time standard deviations are relatively small.

Table 1 gives the matrix of the rank correlation coefficients calculated by Eq. (3) corresponding to 7 dates of measurements.

Dates	(1) 07/09/82	(2) 28/10/81	(3) 02/12/82	(4) 29/07/81	(5) 18/05/81	(6) 16/07/82	(7) 25/08/81
Average storage (mm)	426,81	425,77	424,77	382,06	354,72	347,23	344,46
(1)	1						
(2)	0,953	1					
(3)	0,941	0,953	1				
(4)	0,988	0,961	0,946	1			
(5)	0,953	0,922	0,882	0,968	1		
(6)	0,863	0,789	0,843	0,836	0,882	1	
(7)	0,860	0,824	0,824	0,794	0,863	0,939	1

Table 1 - Site of Grenoble. Matrix of rank correlation coefficient between series of soil water storage measurements obtained on the 17 locations at 7 dates.

A very strong time stability in the ranks of the locations is demonstrated by the highly significant values of r_S (for n = 17 the critical value is 0.748 at the 0.1 % bilateral level).

A similar analysis can be performed on the apparent available water storage values ($A_{i,j}$) computed, for each location, by substracting the smallest water storage observed at that site along the period of measurements (August 17, 1983) from the water storage $S_{i,j}$ at any date. Table 2 gives the ranks of the seventeen locations based on the relative deviations $\bar{\delta}_i$ calculated for both water storage (S_i) and apparent available (A_i) water storage values. The Spearman's test (r_S = - 0.764) leads to consider these two ranks as inverse from each other at a high level of confidence. For instance, note that locations 1 and 4 give always the highest and the smallest water storage and pratically, the smallest and the highest apparent available water storage respectively compared with the field averages.

Locations (i)	(1) (S_i)	(2) (A_i)
1	17	2
2	5	6
3	16	5
4	1	16
5	14	8
6	9	12
7	11	7
8	4	17
9	10	13
10	8	4
11	3	15
12	13	3
13	2	14
14	7	11
15	15	1
16	12	10
17	6	9

Table 2 - Site of Grenoble. Ranks of each measurement location in terms of interannual relative deviation δ_i for water storage (S_i)-column (1), and apparent available water storage (A_i)-column (2).

This may be explained to a large extent by the soil texture profile. As a matter of fact the mean particle sizes smaller than 20 µm within the first meter are 60 % and 49 % for the locations 1 and 4, respectively. Although no particle-size distribution data are presently available for the other locations, one may reasonnably assume that there is a correlation between the silt and clay content of the profile and its water content, and an inverse correlation with the change of water storage everything else being equal. Note also that locations 6, 7, 9, 10 and 14 represent roughly the field average for water storage (fig. 2) and available water storage (table 2).

The same analysis was applied to the data obtained one another experimental site [4].

The main goal of this experiment was to determine water consumption by olive trees under drip irrigation.

Systematic measurements of soil water content and soil water pressure have been made since 1981 by neutron access tubes and tensiometers installed at different distances from selected trees, and replicated over the field. For a treatment with isometric distance of 7 m between trees, a series of 9 locations at a distance of 2.5 and 3.5 m from trees were selected for the purpose of this analysis. It has been shown that at those locations soil water content measurements were neither affected by root extraction nor by irrigation. A time series of 8 data sets was available and was analysed using the relative deviation from the mean as a criteria.

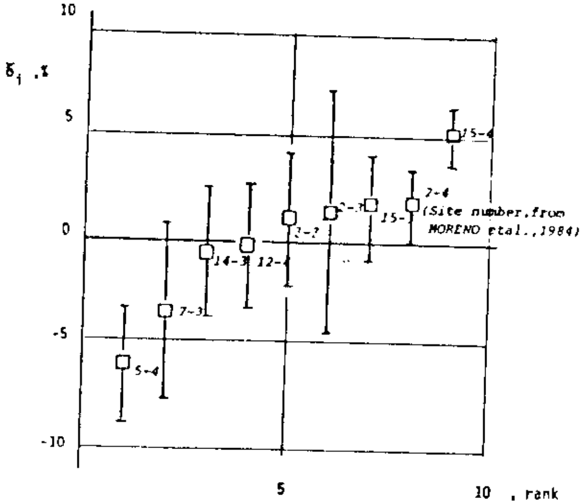

Fig. 3 - Site of Sevilla. Same legend as in Fig. 2

Values of the relative time deviation from the mean storage, and of its associated domain of uncertainty for every site of measurement are given in fig. 3.

The heterogeneity of the field being smaller than in Grenoble, the effect of noise is relatively more important. Once again however the exreme sites conserve their stability with time, the water storage at sites n° 5-4 and 15-4 being respectively 6 % (± 2,8 %) smaller, and 5.3 % (± 1.5 %) higher than the mean value. Two sites (12-4 and 14-3) represent at any time the average water storage with an uncertainty of ± 3 %.

DISCUSSION AND CONCLUSIONS

Apart soil physics, we could easily find other domains where such a time stability exists because of strong covariance between the spatial field of the variable of interest and a deterministic factor. This is the case, for example in watershed studies where rainfall or air temperature are often strongly correlated with elevation or in soil chemistry, where solute carbon concentrations in the soil depend from the immobilization of nitrogen and therefore of the soil specific surface.

For the results presented here, it may be thought that soil retention properties and hydraulic conduction as well, at any depth are highly correlated with the soil texture [5]. Then it becomes clear that the amount of water held in a layer of soil is also dependent on that parameter which can be assumed to be strongly responsible for the time stability of the rank of individual observations in the probability distribution function of the whole population.

The results obtained on two-particular sites tend to show that some spécified locations do represent field average values of water storage and variations of water storage as well. This seems to be in contradiction with the existence of an equivalent uniform soil as defined in [6].

However, it should be remembered that the concept of soil effective properties has been demonstrated to be valid only in cases of steady state flow condition with small fluxes as compared to mean saturated hydraulic conductivity.

In the field conditions reported here, this basic assumption may be considered not too far from the reality.

However, this concept of time stability has to be viewed as a step toward a methodology to reduce a large measurement network to few representative sites. Similar systematic studies in other conditions of soil, climate, vegetation and topography are suggested in order to test more completely this concept.

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PROBLEMS IN ESTIMATING WATER AND SOLUTE MOVEMENT INTO, WITHIN AND THROUGH SOIL WITH MACROPORES

Becher, Hans H.

Dr. H. H. Becher, Lehrstuhl für Bodenkunde, Technische Universität München, Hohenbacherstraße, 8050 Freising-Weihenstephan, W-Germany

Abstract

Macropores - like large cracks and root and earthworm channels - develop and are stable only in cohesive (particularly in clayey) soils. Under unsaturated conditions these macropores are air-filled, so that soil water and soil solute can only move along the walls of macropores and/or within the medium and small pores of the soil matrix. Size and shape of macropores may change due to swelling. Movement conditions make it necessary to distinguish between a mobile and an immobile solute component, and between miscible and immiscible displacement, if solute movement through the soil matrix and its modelling are to be studied. Adsorption and desorption reactions between soil solute and soil colloids must also be taken into consideration. Moreover, the existence of macropores renders to acquire reliable data of soil water and solution for considering and modelling their movements and reactions problematic.

Precipitation can rapidly flow down into deeper soil layers along the walls of the vertical macropores. This causes more rapid changes of soil water tensions and higher soil water contents in the lower subsoil layers than in