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INFLUENCE OF SPATIAL VARIABILITY OF HYDRAULIC CHARACTERISTICS OF SOILS ON SURFACE PARAMETERS OBTAINED FROM REMOTE SENSING DATA IN INFRARED AND MICROWAVES

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Translation of "Influence de la variabilite spatiale des caracteristiques hydrauliques des sols sur les parametres de surface obtenus a partir de donnees de teledetection dans l'infra-rouge thermique et les micro-ondes," Coll. int. Signatures spectrales d'objets en teledetection, Bordeaux, 12-16 Sept. 1983, INRA Colloquia, No. 23, 1984, pp. 772-781

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16. Abstract

The correct interpretation of thermal and hydraulic soil parameters infered from remotely sensed data (thermal infra-red, microwaves) implies a good understanding of the causes of their temporal and spatial variability.

Given this necessity, the sensitivity of the surface variables (temperature, moisture) to the spatial variability of hydraulic soil properties is tested with a numerical model of heat and mass transfer between bare soil and atmosphere.

The spatial variability of hydraulic soil properties is taken into account in terms of the scaling factor. For a given soil, the knowledge of its frequency distribution allows a stochastic use of the model.

The results are treated statistically, and the part of the variability of soil surface parameters due to that of soil hydraulic properties is evaluated quantitatively, in the studied case.

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INFLUENCE OF SPATIAL VARIABILITY OF HYDRAULIC CHARACTERISTICS OF SOILS ON SURFACE PARAMETERS OBTAINED FROM REMOTE SENSING DATA IN INFRARED AND MICROWAVES

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I - INTRODUCTION /772*

This work is based on a dual hypothesis:

- first, remote sensing data in thermal infrared and microwaves (surface temperature and humidity), such as can be obtained near the soil or from an aircraft or satellite, appear spatially very variable at a given instant, on a "meso-scale" and from one parcel to another [1], but also on a more local scale, within the same parcel [2];

- second, the hydrodynamic characteristics of soils (equations for pressure-humidity $h(\theta)$ and hydraulic-humidity conductivity $K(\theta)$) are well known to be very variable in space [3, 4].

Since transfers of mass and energy in soil and atmosphere are related, it is possible to try to discover to what extent the variability of hydrodynamic characteristics is responsible for that of surface parameters.

Next to purely experimental approaches [5], some tentative study approaches on this influence have already been used

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*Numbers in the margin indicate pagination in the foreign text.

successfully with simulation models to describe the spatial variability of soil characteristics using the scaling factor theory [7, 8].

The work described herein was done in this manner, using previous studies on:

- the model itself and its base equations;

- processing results, viewed here statistically.

II - VARIABLE HYDRODYNAMIC SURFACE CHARACTERISTICS

The principle of conservation of mass on the soil surface implies algebraic equality between evaporation flux and soil water flux, which are written respectively:

$$E = \frac{1}{R_v T_M} h_v (p_s - p_a) \tag{1}$$

$$\phi_1 = - E = - (K + D_{vh}) \frac{\partial h}{\partial z} - D_{mT} \frac{\partial T}{\partial z} + K \tag{2}$$

(h_v - convective exchange coefficient for water vapor, function of surface roughness z_o, wind velocity U_a, and the thermal structure of the atmosphere; P_s and P_a - water vapor pressures on the surface and at a reference atmospheric level; R_v - perfect gas constant for water vapor; T_m - average temperature between these levels; z - positively counted portion of the surface; D_{vh} and D_{mT} - diffusion coefficients).

The value of this mass flux is linked to instantaneous climatic conditions, as shown in the energy balance equation: /773

$$R_n = L \cdot E + H + G \tag{3}$$

R_n - density of clear radiation flux; L - latent heat of water vaporization; H - density of measurable heat flux; G - density of heat flux in the soil), with:

$$R_n = (1 - a)R_g + R_a - \varepsilon\sigma T_s^4 \quad (4)$$

$$H = \rho C_p h_h (T_s - T_a) \quad (5)$$

$$G = - D_{cT} \frac{\partial T}{\partial z} - D_{ch} \frac{\partial h}{\partial z} \quad (6)$$

(a and ε - albedo and emissivity of the surface; R_g - solar radiation; R_a - atmospheric radiation, σ - Stefan-Boltzman constant; h_h - exchange coefficient for measurable heat; T_s and T_a - surface temperatures at the reference level; ρ and C_p - volumetric mass and specific heat of the air; D_{cT} and D_{ch} - diffusion coefficients for heat).

Thus, for climatic conditions (R_g, R_a, T_a, P_a, U_a), soil characteristics (a, ε, z_o, K, λ), and given soil conditions ($\partial h/\partial z$, $\partial T/\partial z$), surface variables (T_s and θ_s for example) constantly assume equilibrium values, which thus appear to be a function particularly of:

- values of K and h instantaneously on the surface
- overall behavior of the soil, which will regulate the amount of water and energy on the surface and which can be described with the following conservation equations:

$$C_h(\theta) \frac{\partial h(\theta)}{\partial t} = \frac{\partial}{\partial z} \left((K + D_{vh}) \frac{\partial h}{\partial z} + D_{mT} \frac{\partial T}{\partial z} - K \right) \quad (7)$$

$$C_T(\theta) \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \left(D_{ch} \frac{\partial h}{\partial z} + D_{cT} \frac{\partial T}{\partial z} \right) \quad (8)$$

($C_h(\theta) = \partial h/\partial\theta$ - capillary capacity; $C_T(\theta)$ - volumetric calorific capacity, D_{vh}, D_{vT}, D_{ch}, D_{cT} - diffusion coefficients); these equations lead to the appearance of hydrodynamic characteristics $h(\theta)$ and $K(\theta)$.

III - SPATIAL VARIABILITY AND APPLICATION OF SCALING FACTOR TO POROUS ENVIRONMENTS

For a given level of volumetric humidity θ, hydraulic conductivity K and effective pressure h vary by several orders of magnitude from one soil to another and even in the same soil [3]. If there is a certain number of study and treatment methods for this spatial variability [8], the approach in terms of scaling factor application appears to be of great interest with regard to the work discussed here.

31. Introduction to the scaling factor /774

In the case of two geometrically similar porous environments [9]--one environment (i) and one reference environment (*)--dimensional analysis of the invariability of the surface tension and kinematic viscosity coefficients leads to:

$$\lambda_i \ h_i \ (\theta) = \lambda_* \ h_* \ (\theta) \tag{9}$$

$$\lambda_i^{-2} \ K_i \ (\theta) = \lambda_*^{-2} \ K_* \ (\theta) \tag{10}$$

(λ_i and λ_* being the characteristic lengths of the internal geometry of the two environments).

Thus, by assimilating environment (*) to the scaling average, characteristics $h_i(\theta)$ and $K_i(\theta)$ of any similar environment will be known if average curves $h*$ (θ) and K_* (θ) and the value of (i) in the scaling factor $\alpha_i = \lambda_i/\lambda_*$ are known, since then:

$$h_i \ (\theta) = \alpha_i^{-1} \ h_*(\theta)$$

$$K_i \ (\theta) = \alpha_i \ K_* \ (\theta)$$

Experimentally, it is stated that application of the scaling factor [10], which consists of reducing variables by using the scaling factor, significantly reduces the dispersion of experimental points around the average curves for a given soil: a pedologic unit could thus, in preliminary analysis, be considered as a group of sub-units similar to each other (if this hypothesis were exact, the points would coalesce completely).

The distribution of the scaling factor in the field appears to be normal or, seemingly more often, log-normal [8]: knowledge of an average or a deviation-type is enough to describe it.

32. <u>Consequence for modeling</u>

The introduction of this idea of scaling factor permits relatively easy achievement of the objectives of this work, insofar as knowledge of the distribution law can supply a satisfactory description of the spatial variability of hydrodynamic characteristics.

In this spirit, the projects already mentioned [6, 7] consisted of a study on sensibility of soil-atmosphere transfer models with variations in scaling factor, considered as an entry parameter: analysis was done on the pertinent exit parameters (temperature, humidity, evaporation).

Here we are going to substitute a stochastic approach /775 for this determinant approach, with a view toward supplying not a conservative group of results, but rather statistical distributions and therefore occurrence probabilities of this or that event; this would also make it possible to test the behavior of models which are determinant with regard to the stochastic results.

The procedure followed will therefore be the following:

using a model of paired transfers of mass and energy between bare soil and atmosphere, more complete than preceding models or models which are currently being experimentally validated [11], a satisfactory number of simulations will be done for each case chosen (one hundred, corresponding to that many values of the scaling factor taken in accordance with the distribution law) to be able to consider the output variables as uncertain variables and thu to subject them to the treatments which are standard for the material.

IV - THE SIMULATION MODEL

The model used simulates transfers of water (liquid or vapor) and energy into a soil-atmosphere system limited at its base by a phreatic cover and at its top by an atmospheric level for which the standard meteorological parameters are assumed known: Rg, T_a, P_a, U_a, and precipitation flux (duration, intensity). Transfers in the soil are described by two partial derivative equations, drawn from the theory of Philip and De Vries [12], formulated in pressure and temperature, and modified to allow for a certain number of additional phenomena [13, 14]. They are solved by an implicit diagram of finite differences. The conditions at the upper limit are supplied by simultaneous resolution of mass and energy balances on the surface of the soil. The convective exchange coefficients are formulated from results obtained by Dyer and Hicks [15], Webb [16], and Paulson [17] for stability corrections and Brutsaert [18] for roughness lengths. A detailed description of the model is given in [11].

V - SIMULATION CHARACTERISTICS

51. Soil

The soil chosen for the study is PANOCHE SILT LOAM [19] whose average characteristics are shown in Fig. 1. Calorific capacity and thermal conductivity are calculated according to the De Vries model [20]. Scaling factor α (Fig. 2) follows a log-normal law with parameters:

$$m_{\mathrm{Log}\ \alpha} = -0.616$$

$$_{\mathrm{Log}\ \alpha} = 1.16$$

Albedo and emissivity, functions of soil surface /776
humidity, are shown in Fig. 3. The length of aerodynamic roughness is 1 mm.

52. Climate

Simulations are done under conditions typical for the month of May in Avignon (southeastern France); the daily change in meteorological parameters is shown in Fig. 4.

53. Initial conditions

The initial humidity and temperature profiles are for dry conditions, and a 1.5-m cover is used. Since these profiles are not in balance with the imposed climatic conditions, two days of simulations are included for each case, and only results from the third day on are used.

54. Simulation process

One hundred simulations, lasting one hour, are done for an equal number of scaling factor values in accordance with the distribution law.

VI - RESULTS

The results concern essentially surface variables (temperature, humidity) and evaporation.

Figure 6 shows values measured at 3:00 p.m. for these variables as a function of the logarithm of the scaling factor. Low surface humidity and evaporation are immediately noted; they are due to the dry initial conditions. Humidity varies by more than 1% between the extreme values of the scaling factor, and it decreases steadily as the scaling factor increases. Evaporation increases, but it stabilizes for high values of α: a decrease in humidity following higher evaporation causes a decrease in conductivity; the scaling factor does not increase. This behavior is seen again for accumulated evaporation at the end of the day, which appears as a linear function of Log α over a large part of its distribution (95%). Surface temperature decreases as evaporation increases; it rises again for high values of α: since evaporation there is constant and humidity decreasing, the energy balance can only lead to higher values.

Therefore, evaporation and temperature distributions appear bimodal (fig. 7). The variation coefficient is low for /777 surface parameters (0.5% for humidity, 4.5% for temperature) and higher for evaporation (22% at 3:00 p.m., 27% for the accumulated value).

To find out whether it is possible to characterize the average behavior of a soil using just one value of the scaling factor typical of its distribution, three additional simulations were done with the modal (0.141), median (0.540), and average (1.058) scaling factor values. Figure 8 compares average evaporation obtained during the day with the 100 simulations to the evaporations obtained with these three values of α; Table 1 shows the values, in these four cases, of accumulated evaporation, as well as surface temperature and humidity at 3:00 p.m. A soil whose scaling factor would be equal to the median of its distribution appears thus to have a behavior very near the average behavior of the soil, which confirms a previous result [21].

TABLE 1

	Accumulated Evaporation (mm)	θ_s 3:00 p.m. (%)	T_s 3:00 p.m. (°C)
Average simulation	0.58	5.64	44.66
Determining simulations			
modal (α = 0.141)	0.41	5.96	44.92
median (α = 0.540)	0.57	5.60	44.87
average (α = 1.058)	0.67	5.47	44.62

VII - CONCLUSION

Although, for the simulation conditions used, accumulated evaporation for the day varies from single to triple on the scaling factor variation range, temperature and humidity variations are much smaller: 0.6°C and 1% (corresponding, however, to a change in potential by a factor of 10). These deviations are smaller than the variations commonly observed under natural conditions, which seem to be linked in large part to surface structural heterogeneities. It is stated elsewhere that the dry initial conditions give bimodal distributions of the exit parameters, except for surface humidity.

This work should be done in other simulation conditions, particularly: /778

- under humid initial conditions;
- over a period of several days, which should allow for a much more complete approach to the relationships between the two variability systems.

REFERENCES

1. Hatfield, J. L., Millard, J. P., and Goettelman, R. C. Variability of surface temperature in agricultural fields of central California. Photogrammetric Engineering and Remote Sensing, 48 (8), 1982, pp. 1319-1325.

2. Vauclin, M., Vieira, S. R., Bernard, R., and Hatfield, J. L. Spatial variability of surface temperature along two transects of a bare soil. Water Res. Res., 18 (6), 1982, pp. 1677-1686.

3. Nielsen, D. R., Biggar, J. W., and Erh, K. T. Spatial variability of field-measured soil-water properties. Hilgardia, 42, 1973, pp. 215-259.

4. Vauclin, M., Imberron, J., and Vachaud, G. Spatial variability of some physical properties over one-hectare field plot. AGU Chapman Conf., Fort Collins (Colorado), July 1981.

5. Berge, Ten H.F.M., Stroosnijder, L., Burrough, P., Bregt, A. K., and de Heus, M. Spatial variability of relevant soil physical parameters influencing the temperature of the soil surface. EG3-ESC meeting, Leeds, August 23-27, 1982.

6. Peck, A. J., Luxmoore, R. J., and St..zy, J. L. Effect of spatial variability of soil hydraulic properties in water budget modeling. Water Res. Res., 13 (2), 1977, pp. 348-354.

7. Lascano, R. J. and Van Bavel, C. H. M. Spatial variability of soil hydraulics and remotely sensed soil parameters. Soil Sci. Soc. Am. J., 46 (2), 1982, pp. 223-228.

8. Vauclin, M. Methodes d'etude de la variabilite spatiale des proprietes d'un sol [Methods for studying spatial variability in soil properties]. In: Variabilite spatiale des processus de transfert dans les sols [Spatial variability of transfer processes in soils], Avignon, June 24-25, 1982, Ed. INRA Publ. 1983 (The INRA colloquia, No. 15), 1982, pp. 9-43.

9. Miller, E. E. and Miller, R. D. Physical theory for capillary flow phenomena. J. Appl. Phys., 27, 1956, pp. 324-332.

10. Warrick, A. W., Mullen, G. J., and Nielsen, D. M. Scaling field-measured soil hydraulic properties using a similar media concept. Water Res. Res., 13 (2), 1977, pp. 355-362.

11. Brunet, Y. These de Docteur-Ingenieur [Doctoral Thesis], Universite Scientifique et Medicale de Grenoble, 1984 (to be published).

12. Philip, J. D. and De Vries, D. A. Moisture movement in porous materials under temperature gradients. EOS Trans. AGU, 38 (2), 1957, pp. 222-232.

13. Milly, P. C. Moisture and heat transport in hysteretic /779
inhomogeneous porous media: a matric head based formulation and a numerical model. Water Res. Res., 18 (3), 1982, pp. 489-498.

14. Jury, W. A. and Letey, J. Water vapor movement in soil: reconciliation of theory and experiment. Soil Sci. Soc. Am. J., 43 (5), 1979, pp. 823-827.

15. Dyer, A. J. and Hicks, B. B. Flux-gradient relationships in the constant flux layer. Quart. J. Roy. Meteorol. Soc., 96, 1970, pp. 715-721.

16. Webb, E. K. Profile relationships: the log-linear range, and extension to strong stability. Quart. J. Roy. Meteorol. Soc., 96, 1970, pp. 67-90.

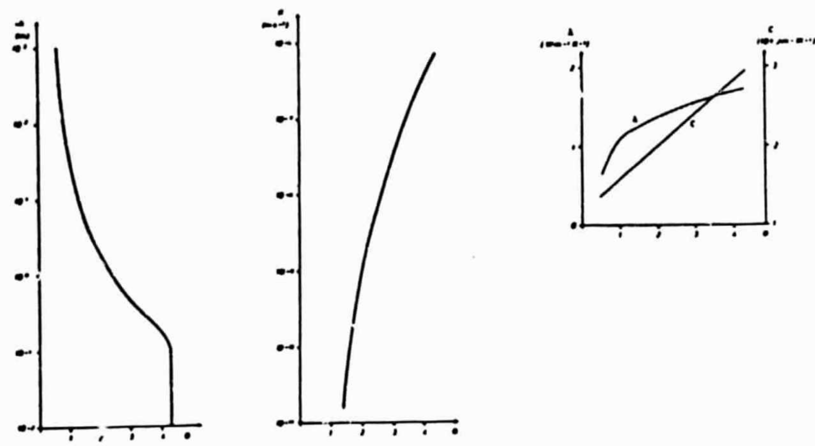
17. Paulson, C. A. The mathematical representation of wind speed and temperature profiles in the unstable atmospheric surface layer. J. Appl. Meteor., 9, 1970, pp. 857-861.

18. Brutsaert, W. The roughness length for water vapor, sensible heat and other scalars. J. Atm. Sci., 32, 1975, pp. 2028-2031.

19. Bresler, E. and Dagan, G. Unsaturated flow in spatially variable fields: 2. Application of water flux model to various fields. Water Res. Res., 19 (2), 1983, pp. 421-428.

20. De Vries, D. A. Thermal properties of soils. In: Physics of Plant Environment, Ed. Van Wijk, North Holland, Amsterdam, 1963, pp. 210-235.

21. Sharma, M. L. and Luxmoore, R. J. Soil spatial variability and its consequence on simulated water balance. Water Res. Res., 15 (6), 1979, pp. 1567-1573.



$$h = h_s \frac{\sigma(T)}{\sigma(T_0)} \frac{1}{\alpha} \left(\frac{\theta - \theta r}{\theta s - \theta r} \right)^{\beta} \; ; \; K = K_s \frac{\nu(T_0)}{\nu(T)} \alpha^2 \left(\frac{\theta - \theta r}{\theta s - \theta r} \right)^{\gamma}$$

$hs = -.15m$
$Ks = 6.11\ 10^{-7} ms^{-1}$
$T_0 = 20°c$
$\theta r = .05$
$\theta s = .43$
$\beta = -2.73$
$\gamma = 7.19$

Figure 1. Average transfer characteristics for Pancche Silt Loam.

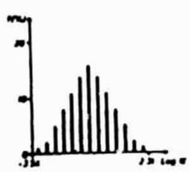


Figure 2. Scaling factor distribution.

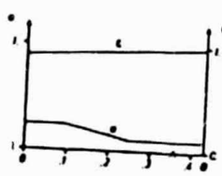


Figure 3. Albedo and emissivity.

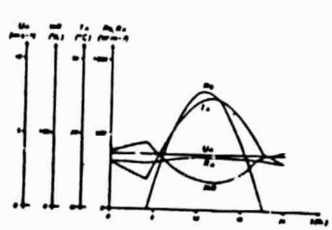


Figure 4. Climatic characteristics of the simulations.

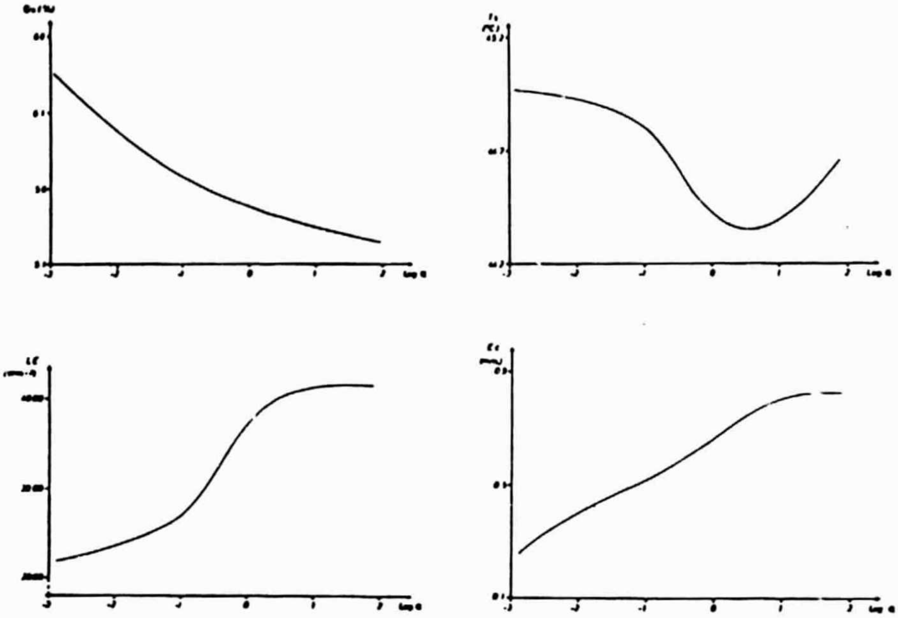


__Figure 5__. **Average temperature, humidity, and evaporation at 3:00 p.m.; average accumulated evaporation for the day.**

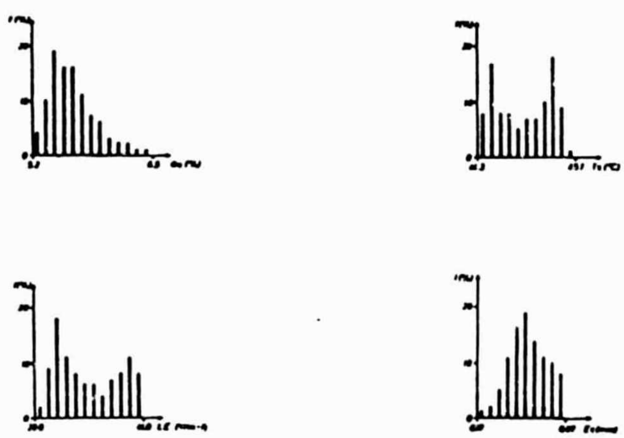


__Figure 6__. **Distributions of temperature, humidity, and evaporation at 3:00 p.m., and of accumulated evaporation for the day.**

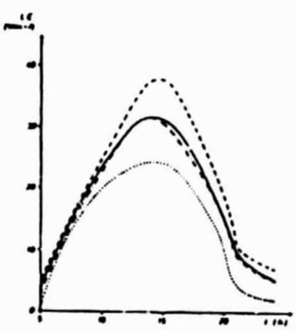


__Figure 7__. **Daily change in evaporation:**

- **average (————)**
- **determining**
  - **α modal = 0.141 (.......)**
  - **α median = 0.540 (-.-.-.-)**
  - **α average = 1.058 (-------)**