Spatial variability of land surface processes under programme: climate

Final report

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EXECUTIVE SUMMARY

This is the final report from the Dutch component of the CEC project entitled 'Spatial Variability of Land Surface Processes' (SLAPS I).

The report starts with the Introduction in which the Dutch contribution is outlined. In the successive chapters the activities are described in a concise way. Extended descriptions of the studies can be found in the reports and articles referred to.

Although each chapter discusses a single topic, they are strongly interconnected by the overall objectives of the contribution.

Chapter 2 to 5 have been given more or less the same structure. Chapter 2 presents work on the application of scaling to account for soil hydraulic variability in a statistically homogenous soil. Chapter 3 reports on a new measurement technique and its critical evaluation for estimating soil hydraulic properties.

In Chapter 4 the first results are discussed on the estimation of regional 'effective' hydraulic properties, by using the Inverse Method.

Chapter 5 concentrates on large scale land surface parameterizations and their testing. To two studies, on pedo-transfer functions and climate change respectively, attention is paid in Chapter 6.

Chapter 7 contains a summary of conclusions and an evaluation. A listing of written documents and presentations is given in Appendix I and II.

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The following persons contributed to the project by means of one or more official publications or by technical assistance.

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| 3) | Fully financed by the Commission from January 1991 - August 1992 |
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CONTENTS

EXECUTIVE SUMMARY

PARTICIPANTS

| 1 | INTR | ODUCTION | 1 |
|---|------|---|----|
| | 1.1 | Context | 1 |
| | 1.2 | Scope of the project and contribution | 1 |
| | 1.3 | Outline of the report | 2 |
| 2 | SPAT | IAL VARIABILITY | 4 |
| | 2.1 | The problem | 4 |
| | 2.2 | The scaling approach | 4 |
| | 2.3 | Application and results | 5 |
| | 2.4 | Concluding remarks | 8 |
| 3 | MEAS | UREMENT OF SOIL HYDRAULIC PROPERTIES | 10 |
| | 3.1 | Problem and approaches | 10 |
| | 3.2 | One-Step outflow method | 10 |
| | 3.3 | Multi-Step outflow method | 13 |
| | 3.4 | Experimental data sets | 15 |
| | 3.5 | Concluding remarks | 16 |
| 4 | THE | INVERSE MODELLING APPROACH FOR REGIONALIZATION OF | |
| | SOIL | MOISTURE TRANSPORT | 17 |
| | 4.1 | Problem and approach | 17 |
| | 4.2 | Application and results | 17 |
| | 4.3 | Concluding remarks | 20 |
| 5 | LAND | SURFACE CODES IN ATMOSPHERIC MODELS | 22 |
| | 5.1 | Problem and approaches | 22 |
| | 5.2 | Testing of some land surface codes | 23 |
| | 5.3 | Concluding remarks | 23 |

| 6 | ADDIT | TIONAL STUDIES | 27 | | | |
|------------------------------|--------|---|----|--|--|--|
| | 6.1 | Estimation of soil physical properties by | | | | |
| | | pedo-transfer functions | 27 | | | |
| | 6.2 | A case study of climate change effects | 27 | | | |
| | | | | | | |
| 7 CONCLUSIONS AND EVALUATION | | | | | | |
| | 7.1 | Conclusions | 30 | | | |
| | 7.2 | Evaluation of objective | 31 | | | |
| Refer | ences | to Chapters 2 to 6 | 32 | | | |
| Appen | dix I | : Publications related to the project | 33 | | | |
| Appen | dix II | : Presentations related to the project | 35 | | | |

1 INTRODUCTION

1.1 <u>Context</u>

Within the CEC-Climatology Programme an international project was financed, entitled 'Spatial Variability of Land Surface Processes'. It brought together several research groups from the atmospheric and hydrologic community in order to make a joint scientific effort on an unsolved problem in larger scale atmospheric/hydrological modelling.

1.2 Scope of the project and contribution

The unsolved problem may be defined as follows. Terrestrial hydrologic processes like rainfall, infiltration rate, surface runoff, soil water flow and evapotranspiration vary in time and space. Numerical climate models are computationally characterized by relatively small time steps (\approx 15 min) and large grid sizes (\approx 300 km or more).

Although the mentioned hydrologic processes encounter certain conceptualization problems related to the, let say, 15-min time scale, it is felt that the main problems are connected with the question of how to parameterize processes at a certain spatial scale and how to account for sub-scale variability.

The contribution of the 'Wageningen' group focuses on the role of subsurface flow in hydrologic modelling with special attention to spatial variability of soil hydraulic characteristics.

Soil moisture availability, a crucial factor in climate models, depends mainly on the hydraulic properties of the soil. However, climate models need in principle simple parameterizations of processes. These two facts lead to the following two-step approach. Develop methods for representing variability of soil hydraulic properties in physically based subsurface flow models and, preferably if possible, derive soil-effective properties. Secondly, search for (scale-dependent) parameterizations and validate them against the physically based approach. This two-step approach is the central idea in the Wageningen contribution (see Fig. 1.2.1). Part of its realization forms the main objective of the here reported work.



A WORK HYPOTHESIS ON SOIL MOISTURE CODES

Fig. 1.2.1 Flow diagram on testing and improving large scale soil moisture parameterizations.

1.3 Outline of the report

The effect of spatial variability on the subsurface hydrologic regime at small catchment scale is described in Chapter 2. The apparently successful application of a scaling approach in that study led to the necessity of further validation on other soils and spatial scales. This posed a measurement problem on which will be reported in Chapter 3.

Partly as a consequence of the outcome of Chapter 3 and partly by ideas, expressed in literature, the Inverse Modelling approach is further investigated in Chapter 4, being a potential tool for deriving areal effective parameters in classical models. Referring to Fig. 1.2.1, Chapter 2 to 4 are related to the left hand side of the flow-diagram, while Chapter 5 on parameterizations is related to the right hand side.

In Chapter 5, also in relation to future plans, attention is paid to some

land surface parameterizations in existing climate models.

Chapter 6 contains some miscellaneous studies. The usefulness of pedotransfer functions, as an alternative to the physical based measurement techniques for estimating soil hydraulic properties, is discussed. Also some work on climate change effects upon the hydrologic behaviour of a small Dutch catchment is reviewed.

Chapter 7 contains the conclusions which can be drawn from the results and an evaluation of the objectives of the study. Appendix I and II give an overview of publications and presentations of the participants contributing to the project.

2 SPATIAL VARIABILITY

2.1 <u>The problem</u>

Vertical soil water movement follows the so-called Richards equation for quantifying the flow.

The equation is highly non-linear in a mathematical sense due to the definition of the soil hydraulic properties on which the solution of the equation depends. The properties are the water retention function $(h-\theta)$ and the hydraulic conductivity function $(k-\theta)$. Determination of these functions has been and still is a point of major attention in soil physical/hydrological studies.

It appears from field studies (Warrick et al., 1977, Hopmans & Stricker, 1986) that these functions show a large spatial variation, even over small length scales. This poses the problem how to implement or account for this variability in computational studies on soil water movement and how to collect the set of soil hydraulic functions.

2.2 Scaling approach

Spatial variation of the soil hydraulic properties can be expressed by scaling factors. The use of scaling factors originates from the work of Miller & Miller (1955) who introduced the similar media concept for porous media. The concept states that similar soils only differ in the scale of their internal microscopic geometries and have equal porosities.

Following Hopmans (1987) we define a scaling factor α_r as the ratio of the macroscopic length scale λ_r of a soil at position r and the characteristic length λ_m of a reference soil:

 $\alpha_r = \lambda_r / \lambda_m$ for $r = 1, \ldots, N$

From the similar media concept it follows that for a given water content, θ , at any location r the soil water pressure, h_r , can be expressed as

$$h_r = h_m / \alpha_1$$

and the hydraulic conductivity $\boldsymbol{k}_{\mathrm{r}}$ as

 $k_r = k_m a_r^2$

where h_m and k_m are the values of the reference soil for that particular water content. However soils are not fully similar, neither have equal porosities. Thus, instead of using water content, h and k are written as functions of the degree of saturation S: $S = (\theta - \theta_r)/(\theta_s - \theta_r)$, where θ_r is the residual and θ_s the saturated water content.

Given now a set of observed hydraulic functions from soil samples of a statistical homogeneous soil the objective is to derive by mathematical means the $k_m(S)$ and $h_m(S)$ reference curves and a set of scaling factors α_r . This is done by optimization techniques. Scaling factors may obey a certain probability density function.

To characterize the spatial variation of the hydraulic properties of a soil one ends up with reference curves for k and h, as function of S, a probability distribution for the scaling factors and a probability function of θ_{s} .

2.3 Application and results

In the experimental catchment Hupselse Beek water balance studies were undertaken over a length of years. To study the unsteady water flow in the unsaturated zone of the whole catchment an intensive measurement campaign was undertaken to collect experimental $h(\theta)$ and $k(\theta)$ data. These data were taken from undisturbed soil samples for three horizons and at three different spatial scales. Full account of the applied methods and results of the measurements was given by Hopmans and Stricker (1986). The measured hydraulic data, both for water retention and conductivity, were fitted to the closed-form Mualem-Van Genuchten expressions (1978).

Once the fitting was done, the curves were scaled for the saturation degree instead of water content.

Fig. 2.3.1 and 2.3.2 show the results of scaling. Both the reference h(S) and k(S) lines have been drawn. The scaling factors, α_r , appeared to be lognormally and the saturated water content, θ_s , normally distributed. θ_s and α_r have been proven to be statistically independent.



Fig. 2.3.1 Unscaled (a) and scaled (b) retention data.



Fig. 2.3.2 Unscaled (a) and scaled (b) conductivity data.

With these ingredients stochastic analysis of the one-dimensional unsaturated flow can be accomplished. Departing from a dynamic onedimensional numerical model we generate a representative sample of soil profiles by applying Monte Carlo techniques to the α - and $\theta_{\rm g}$ -distributions. Each randomly generated soil profile is used in the selected numerical model to produce the water balance terms over chosen time intervals. This application has been done for the Hupselse Beek catchment and is fully described by Hopmans & Stricker (1989). One of the additional complicating factors in this study was formed by the shallow groundwater levels in the watershed, influencing the vertical waterbalance at the lower boundary. This complication was solved by introducing an extra scaling procedure for the discharge-groundwater level relationship, q(h).

Another complication was the occurrence of a 'boulder' clay-horizon in the profile which may hamper upward flow to the rootzone. This resulted in an areal map of the catchment showing the distribution of the profile types (see Fig. 2.3.3).

entege of profile types with different starting denths to clay

| Depth to clay (m) | < 0.4 | 0.4-0.8 | 0.8-1.2 | 1.2-1.6 | > 1. 6 34 | | | | | | |
|-------------------|-------|---------|---------|---------|---------------------|--|--|--|--|--|--|
| Arear percentage | 4 | 240 | 41 | 14 | 94 | | | | | | |



Fig. 2.3.3 Distribution of profile types over the area and in percentages in the Hupselse Beek catchment.

For each of the five soil profile types (see Fig. 2.3.3) 30 Monte Carlo simulations were performed for the growing seasons of 1982 and 1976, a dry and a very dry year respectively.

One outcome of the study is demonstrated in Fig. 2.3.4. Here the average reduction of actual evapotranspiration has been presented as a result of depth to clay. Also the standard deviation of E_{act} has been given for identical clay profiles but randomly generated α_r , θ_s and q(h).



Fig. 2.3.4 Distribution of soil classes as a result of Monte Carlo simulations. For each class the mean reduction (μ) of E_{act} has been given together with the standard deviation (σ) .

2.4 <u>Concluding remarks</u>

From the results of the study of Hopmans & Stricker (1989) it appeared that a stochastic-deterministic approach for vertical one-dimensional soil water flow is a feasible way for regionalizing unsaturated flow and soil moisture distribution. In this approach scaling or functional normalization (Tillotsen and Nielsen, 1984) of the spatially variable hydraulic properties plays a key-role.

Applicability of the method strongly depends on a fast and reliable technique to determine an experimental set of soil hydraulic properties of a particular soil, in order to be able to derive h(S) and k(S)-reference curves together with a probability density function for the scaling factors and a probability density function for θ_s .

In the next chapter such a technique will be discussed.

3 MEASUREMENT OF SOIL HYDRAULIC PROPERTIES

3.1 <u>Problem and approaches</u>

As stated in Chapter 2 a fast and reliable technique is needed to determine a large experimental data set of hydraulic properties. This set should be large enough to enable a statistical analysis for the determination of the probability density functions of the scaling factors and θ_s .

Many methods or techniques have been proposed in literature, partly field-, partly laboratory-oriented. In the last case undisturbed soil samples have to be taken. However, all the methods have some disadvantages like time consumption, limited range of application or theoretical restrictions.

More recently a new approach has been proposed together with the outflow method. It is based on inverse modelling technique and it needs operationally an experimental laboratory set-up, a simulation model for unsaturated flow, an optimization algorithm, computing facilities and closed-form analytical expressions for the retention- and hydraulic conductivity curves.

The outflow method as we have applied, was first proposed by Kool et al. (1985) and is generally referred to as the One-step outflow method. A thorough study of the method is reported in section 3.2 and a modified, improved version is discussed in section 3.3.

3.2 <u>One-step outflow method</u>

The method can be described as follows. An undisturbed soil sample is placed in a Tempe pressure cell on top of a ceramic plate (Fig. 3.2.1). The soil sample is saturated and the outflow experiment starts by increasing pneumatic pressure at top of the sample. This induces unsaturated flow in the soil sample while the ceramic plate stays saturated. Cumulative outflow $Q_o(t)$ is recorded in the burette. This procedure of installing the sample, saturation and outflow measurements can be done in 5 days. The experiment is not labour-intensive and simultaneous measurements can be done for a number of samples, each of them installed in a pressure cell.

The simulation model is a numerical flow model based on Richards' equation: $\delta\theta/\delta t = \delta[k(h) (\delta h/\delta z - 1)]/\delta z$



Fig. 3.2.1 Cross-section of Tempe-pressure cell.

where z is the vertical coordinate, downward positive and zero on top of the sample.

The boundary conditions for which the equation should be solved numerically are:

$$t = 0 \qquad h = h_0(z) \qquad 0 \le z \le L$$

$$t > 0 \qquad \delta h/\delta z = 1 \qquad z = 0$$

$$t > 0 \qquad h = h_L - h_a \qquad z = L$$

where L is the height of the sample plus ceramic plate, h_L is the initial moisture potential below the ceramic plate and h_a is the applied pneumatic pressure. To be able to solve Richards equation the soil hydraulic functions have to be known. In our case the analytical description of the function is according to Van Genuchten-Mualem (1980). This implies that at least three empirical shape-parameters (α , n, 1) have to be estimated enabling quantification of the retention- and conductivity expressions. However, it turned out that the saturated hydraulic conductivity, K_{sat} , should also be taken as unknown, becoming a fitting instead of a physical, measurable, quantity.

With the numerical model and the analytical expressions, the outflow from the soil sample can be simulated by making a first guess of the parameters and one or more quantities. By comparing the simulated outflow with the experimentally measured outflow and making use of an optimization algorithm one may be able to find a final fit between both outflows. This yields the best estimates of the unknown parameters and quantities in the Van Genuchten-Mualem expressions.

Van Dam et al. (1990, 1992a) explored the method thoroughly on several sources of errors, on non-uniqueness and on instability of the estimated parameter values. This was done for four types of soil and for each soil it comprised circa fifteen samples. As a reference also independent methods for determination of the hydraulic functions were applied to the soils. Separately, soil water retention data were collected for the soil samples. For the One-step outflow method several combinations of unknown parameters and quantities in the hydraulic expressions were investigated. See table 3.2.1.

Table 3.2.1 Different methods of estimating k(h) from One-step outflow data.

| number optimiza | data objective function tion | fixed | optimized |
|--------------------|---------------------------------|-------|---------------------------------------|
| 1 | Q(t) | • | $\alpha, n, \theta_s, K_s, I^{(1)}$ |
| 2 | $Q(t) + \theta(h)$ | - | $\alpha, n, \theta_s, K_s, I^{(1)}$ |
| 3 | $Q(t) + \theta(h)^{(2)}$ | - | $\alpha, \pi, \theta_s, K_s, I^{(1)}$ |
| 4 | Q(t) | θ(h) | K.,1 |
| 5 | Q(t) | θ(h) | $\alpha^{(3)}, n^{(3)}, K_s, 1$ |

Boundaries as set 1 in Table 4
 Extra weight

(3) These parameters are independent from those of the retention function

From this study it is concluded that single use of outflow data, Q(t), from the One-step method leads to non-unique and incorrect estimates of the hydraulic functions. This may be demonstrated by Fig. 3.2.2 (a to d).

Although the optimized functions predict the measured outflow equally well, the functions differ substantially.

Supplement of independently determined retention data to the outflow data yields much more reliable results. In fact the $\theta(h)$ data are needed to get unique solutions.





3.3 <u>Multi-step outflow method</u>

The combination of the One-step method (sudden pneumatic pressure increase from zero to 1 bar) with independent measurements of retention data for getting unique solutions is not a very attractive alternative, as it is a time consuming procedure.

An intermediate approach, proposed by Van Dam et al. (1990, 1992a) is to increase the pneumatic pressure step by step from zero to 1 bar. The outflow is measured with respect to time and the flow process approximates steady state at the end of each step.

Cumulative outflow from 18 different soil samples of a loamy soil are visualized in Fig. 3.3.1 for the One-step method (a) and the Multi-step method (b). Of course, the outflow process for the last case is more time consuming, but it contains considerably more information for the optimization process to end up with a unique set of hydraulic parameters for the Van Genuchten-Mualem hydraulic functions.



Fig. 3.3.1 Cumulative outflow as a function of time for (A) the One-step experiment, and (B) the Multi-step experiment.

The vertical variation of the points resembles the spatial variation of the hydraulic properties of the 18 samples, which trigger the outflow process. A full description of the experimental set-up and results can be found in Van Dam et al. (1992b). Beside the outflow experiments also determination of the retention curves were independently done for the 18 samples. These data offered subsequently the possibility to validate the Multi-step method for estimating correctly $h-\theta$ (and, simultaneously, $k-\theta$ relation).

Fig. 3.3.2 shows a typical example of the results from the different methods.

As can be seen the estimated curve by the One-step deviates completely from the equilibrium, while the Multi-step estimates the equilibrium data quite well.

Another encouraging result is shown in Fig. 3.3.3 in which the results for different combinations of optimized variables are presented for the retention curve, taking all 18 samples together. Again, the Multi-step

approaches behave well with respect to the equilibrium line, while the Onestep result **lies far apart**.



Fig. 3.3.2 Retention function of a typical sample. Shown are equilibrium (+) data and the estimated curves from the One-step and the Multi-step experiment.



Fig. 3.3.3 Retention curves optimized by One-step method and Multi-step method. In the last case two different sets of parameters in Mualem-Van Genuchten were optimized and one on the averaged outflow of all samples.

3.4 Experimental data sets

In order to be able to follow successfully the strategy, as set out in Fig. 1.2.1, several data sets of soil physical functions from different soil types have to be realized. The data set of the Hupselse Beek catchment has

already been mentioned and was realized outside the project. Part of the project was a field campaign to the Hapex-Mobilhy area in South-West of France for collecting a large set of undisturbed soil samples for the two main soils in the area. A set of 46 and 47 h- θ and k- θ curves for respectively a sandy and a loamy soil were determined. For the sandy samples it was still done by applying the One-step method but with independent retention data and for the loamy soil by the Multi-step method. Full description of the data sets is given in the reports of Droogers (1990) and Kim (1991).

3.5 <u>Concluding remarks</u>

In search of a fast and reliable measurement technique to determine soil hydraulic properties it was found that the One-step outflow method, as it was proposed in literature, does not yield unique results.

It only works if additional information is delivered to the optimization process like retention data of the same soil sample.

However a good alternative is offered by the Multi-step outflow method, tested for different soil types. The method is still fast enough to enable the realization of relatively large data sets of soil hydraulic properties. 4 THE INVERSE MODELLING APPROACH FOR REGIONALIZATION OF SOIL MOISTURE TRANSPORT

4.1 Problem and approach

As already stated in Chapter 1, section 1.2, spatial variation of soil hydraulic properties plays an important role in regional estimates of soil moisture movement.

In Chapter 2 and 3 we concentrated on the tools for describing and fastly measuring the spatially variable properties.

However, from the catchment study it appeared that the computational effort to produce areal mean values of the water balance terms as a result of spatial variation of the hydraulic properties is a quite laborious task, using Monte Carlo techniques.

So, we explored the possibilities to derive effective soil hydraulic properties by inverse modelling and by use of the reference curves, obtained by scaling, both in order to describe the regional behaviour of the unsaturated waterflow by classical theory.

4.2 Application and results

Again soil hydraulic data of 32 samples from the Hupselse Beek catchment were used. For these data the reference curves were already derived earlier (see Chapter 2). Furthermore, two one-dimensional numerical simulation models (SWACROP and SFIT) for unsaturated flow, the closed-form analytical expressions of Van Genuchten-Mualem and an optimization routine in SFIT were used.

A schematic outline of the study by Feddes et al. (1992) is given in Fig. 4.2.1.

First for a bare soil surface the areally averaged water contents and evaporative fluxes from the 32 profiles were computed. Then, 'effective' single column soil hydraulic functions were generated by inverse modelling for three fitting data sets:

- water contents at several depths and selected times
- cumulative evaporation/infiltration versus time
- cumulative evaporation/infiltration versus time plus water content at
 0.5 cm depth at selected times.



Fig. 4.2.1 Phase 1; calibration and testing of effective soil parameters from a numerical experiment for bare soil.

Besides these optimization results, the $h-\theta$ and $k-\theta$ reference curves by scaling were available.

Some testing in Phase I (see Fig. 4.2.1) revealed that results from the inverse modelling on water contents (preserving both soil moisture distribution and conservation) performed better than the results from the inverse modelling on cumulative evaporation/infiltration data. Striking was the close agreement between the effective hydraulic properties resulting from water content-fitting and the reference curves by scaling.



Fig. 4.2.2 Phase II; validation test for a vegetated surface, using SWACROP.

In Phase II (see Fig. 4.2.2) of the study a relative validation was made by comparison of simulation results with the model SWACROP. One set of results was produced by averaging the individual output of simulations with 32 columns and other data sets resulted from individual simulation runs for the different 'effective' soil profiles by inverse modelling and of the reference profile.

The simulations were done for a vegetated surface. Meteorological time series of the dry summer of 1982 and the very dry summer of 1976 were imposed as forcing at the upper boundary of the model.

Thus, the validation conditions were completely different from the artificial testing conditions.

As an example, some of the results are listed in Table 4.2.1.

It shows the good agreement between all cases considered for simulating the cumulative actual evapotranspiration.

Table 4.2.1 Summary of SWACROP simulations of the grass covered soil over the period 1 April to 1 October of the extremely dry year 1976 and the fairly dry year 1982

(mean - 32 profiles (validation data); refer = reference profile by scaling; profile = 'effective' soil by optimizing on θ -profiles; Evap = 'effective' soil by optimizing on **Evaporation only**).

| | Cumulative actual transpiration (cm) | | | | | | | | | | |
|-------|--------------------------------------|---------------------|-------|---------------|-------|-------|-------------|---------------|--------|-------|--|
| Daynr | Mean | 1976 <std></std> | Refer | Profil | Evap | Mean | <std></std> | 1982 Refer | Profil | Evap | |
| 120 | 4.13 | 0.141 | 4.13 | 4.16 | 4.08 | 3.81 | 0.025 | 3.82 | 3.82 | 3.77 | |
| 150 | 8.76 | 0.771 | 8.61 | 8,82 | 9.20 | 9.48 | 0.207 | 9.51 | 9.54 | 9.25 | |
| 180 | 13.82 | 1.213 | 13.60 | `13.91 | 14,34 | 13,81 | 0.813 | 13,66 | 13,90 | 14.07 | |
| 210 | 16.19 | 1.283 | 15.94 | 16.26 | 17.22 | 18.89 | 1.343 | 18.58 | 18.95 | 18.88 | |
| 240 | 19.23 | 1.495 | 18.95 | 19.34 | 19.99 | 21.13 | 1.336 | 20,86 | 21.22 | 21.64 | |
| 270 | 21.48 | 1.334 | 21.31 | 21.63 | 22.28 | 24.65 | 1.333 | 24.45 | 24.81 | 24.82 | |

| | Cumulative flow to the groundwater-table (cm) | | | | | | | | | | | |
|-------|---|---------------------|-------|--------|------|------|-------------|---------------|--------|------|--|--|
| Daynr | Mean | 1976 <std></std> | Refer | Profil | Evap | Mean | <std></std> | 1982 Refer | Profil | Evap | | |
| 120 | 0.85 | 0.059 | 0.85 | 0.84 | 0.75 | 0,85 | 0.054 | 0.85 | 0.84 | 0.78 | | |
| 150 | 1.24 | 0.186 | 1.19 | 1.19 | 1.05 | 1.35 | 0.145 | 1.30 | 1.30 | 1.21 | | |
| 180 | 1.44 | 0.275 | 1.34 | 1.34 | 1.05 | 1.64 | 0.291 | 1.55 | 1.55 | 1.38 | | |
| 210 | 1.56 | 0,338 | 1.43 | 1.43 | 1.09 | 1,81 | 0.291 | 1.68 | 1.68 | 1.50 | | |
| 240 | 1.64 | 0.386 | 1.49 | 1.49 | 1.12 | 1.92 | 0.334 | 1.77 | 1.77 | 1.50 | | |
| 270 | 1.70 | 0.426 | 1.53 | 1.53 | 1.14 | 2.00 | 0.370 | 1.83 | 1.84 | 1.60 | | |

| | Volumetric water content at 1.5-cm soil depth | | | | | | | | | |
|-------|---|---------------------|-------|--------|-------|-------|-------------|---------------|--------|-------|
| Daynr | Mean | 1976 <std></std> | Refer | Profi1 | Evap | Mean | <std></std> | 1982 Refer | Profil | Evap |
| 120 | 0.077 | 0.058 | 0.053 | 0.075 | 0.123 | 0.186 | 0.072 | 0.159 | 0.187 | 0.194 |
| 150 | 0.221 | 0,073 | 0.192 | 0,218 | 0,201 | 0.108 | 0.067 | 0.080 | 0.106 | 0.128 |
| 180 | 0.064 | 0.051 | 0.048 | 0.067 | 0.068 | 0.262 | 0.075 | 0.231 | 0.259 | 0.241 |
| 210 | 0.165 | 0,068 | 0,140 | 0.164 | 0.145 | 0.059 | 0.048 | 0.048 | 0.066 | 0.072 |
| 240 | 0.064 | 0.044 | 0.053 | 0.067 | 0.080 | 0.206 | 0.071 | 0.179 | 0.205 | 0.186 |
| 270 | 0.144 | 0.065 | 0.121 | 0.145 | 0.131 | 0.172 | 0.067 | 0.148 | 0.172 | 0.155 |

4.3 <u>Concluding remarks</u>

In this Chapter the work has been discussed that was done on investigating the usefulness of areally representative or 'effective' soil hydraulic functions in the classical flow model (Richards equation).

One conclusion that can be drawn from the study is that inverse modelling opens perspectives to find effective parameters, provided certain conditions like absence of surface runoff and the availability of areally averaged moisture profiles for optimization.

Further, a striking point was that in both phases of the study the results of simulations by using the reference parameters from scaling were well

comparable to the averaged behaviour of the 32 profiles. This would indicate the possibility of using reference curves as 'effective' curves for a, statistically, homogeneous soil type. Both concluding remarks are points for further exploration.

5 LAND SURFACE CODES IN ATMOSPHERIC MODELS

5.1 <u>Problem and approaches</u>

In atmospheric models, like weather prediction models and General Circulation Models, the atmospheric and hydrologic processes are coupled at and near the earth's surface. This coupling is necessary because it is generally agreed that there is a strong interaction in the behaviour of the atmosphere and the hydrologic land surface processes. As an example, the partition of net energy at the surface is directly triggered by the soil moisture availability at and below the soil surface. A relatively high latent heat flux will lead to a higher chance of cloud formation and, by that, to a higher chance of rainfall at the surface. This is one example of numerous feed-back mechanisms in the land-atmosphere system, in which hydrology plays an important role.

Recognizing this, it is evident that the representation of the hydrologic processes in atmospheric models should be an area of study.

Two main problems arise with respect to the coupling of atmospheric and hydrologic processes.

The first can be related to non-coinciding length- and time-scales. Atmospheric models are common to work at much larger length-scales and at much smaller time-scales than hydrologic models.

The second problem focuses on the 'art' of parameterization of processes. Due to the large spatial scales and small time-scales over which atmospheric models normally integrate, hydrologic modelling has to adapt to that scales by use of 'simple' parameterizations.

Parameterizations are scale-dependent. Inherently to their nature, they will integrate implicitly for effects at sub-scale level, whether it is in space or time.

Suppose we have a reliable, well tested, parameterization, acting at a certain time- and length-scale. Looking for parameterization at a larger spatial scale. approach may be one to use the already tested parameterization for the smaller scale as a reference for the proposed larger scale parameterization. In that case we have to account for the variability which the intra-scale is manifest to smaller scale parameterization and should be integrated in the larger scale parameterization. One way to do so is by introducing a stochastic component

to the small scale model, whereby this component accounts for the description of the intra-scale variation. This approach is proposed here and, again, is depicted in Fig. 1.2.1, with the emphasis now on the right hand side of the figure.

5.2 Application and results

Two large scale parameterizations for representing the terrestrial hydrologic processes in atmospheric models were investigated. The most simple one is the so called Bucket-model as described by Warrilow (1986). It is a single soil layer from where water can go in and out by rainfall, evapotranspiration and percolation. The second model is the Deardorff-model (1977) as modified by Noilhan & Planton (1989). It is an embedded two layer model and also in the description of the relevant processes more complicated than the first one. However, the model is closed at the lower boundary prohibiting percolation.

For three periods of 180 days, representing wet, moderately dry and dry meteorological conditions the Bucket- and Deardorff-models were applied together with a physically based, transient flow model, SWATRE. The last model was repeatedly run to account for smaller scale soil variability by using scaling and Monte Carlo techniques. Data came from the 'Hupselse Beek' catchment. Results of this type of study have been presented at the EGS-meetings in Copenhagen (1990) and Edinburgh (1992).

As an example, in Fig. 5.2.1 cumulative results have been depicted for potential and actual evapotranspiration. The overall conclusion from these simulations is that the large scale parameterizations are too optimistic in estimating the available amount of water for the evapotranspiration process. Furthermore it is remarkable how relatively well the simple Bucket model behaves compared to the Deardorff-model.

5.3 <u>Concluding remarks</u>

Land surface parameterizations in meteorological models have to be computationally fast and should have a limited number of areally representative parameters.



Fig. 5.2.1 Cumulative Potential Evapotranspiration and Actual Evapotranspiration for three models for three different growing seasons. P is precipitation over 180 days.

Physically based, one-dimensional flow models do not yet accomplish the first condition. Regarding the second condition, they have a limited number of parameters (two hydraulic functions) but these parameters do vary substantially in space.

Simple conceptual parameterizations respond to the first condition, and have in general a limited number of parameters of which the quantification is quite an artifact and suggest, not proven, to possess some areal representation. In fact, for the last category of models it is tacitly supposed that the land surface hydrology is so complex and variable at small spatial scales, that at larger scale it will integrate or average out (in a kind of analogy to the law of large numbers in statistics) to simple regression type formulations governing the water balance. So, to examine these parameterizations critically on their behaviour under a variety of system and boundary conditions and to improve them where possible, should be a major objective of the hydrological community. During the project period an initiative was taken to plan a broad intercomparison study on a variety of Land Surface Codes, as used in climate models and available from hydrologists.

An outline of the aimed activities is presented in Fig. 5.3.1 in the form of a flow diagram. Steps 1 to 6 are under execution now within the EC-SLAPS II project.



Fig. 5.3.1 Scheme of intercomparison study of Land Surface Codes.

6 ADDITIONAL STUDIES

6.1 <u>Estimation of soil physical properties by pedo-transfer functions</u>

To describe quantitatively soil water flow by Richards equation the hydraulic functions, $h-\theta$ and $k-\theta$ have to be known. Although there are several field and laboratory methods for estimating the functions they are in general time consuming and/or expensive. As a good alternative the Multi-step method has been proposed (see Chapter 3). However, the whole procedure to determine the functions would be further simplified if one or both functions could be allocated by relating them to textural characteristics of the soil or soil sample.

In our case we used a set of textural data of 72 soil samples from the experimental catchment 'Hupselse Beek'. With these samples also One-Step outflow experiments were conducted.

The set-up of the study was to derive field mean hydraulic functions by a combined use of the pedo-transfer approach to estimate separate and mean retention curves and the outflow to estimate separate and mean conductivity curves.

The results could be compared with an independently determined mean retention curve from an earlier study (see Chapter 2). The pedo-transfer approach can be either empirical, using regression equations between textural data and the parameters describing analytically the retention curve, or semi-empirical, based on shape similarity between the retention curve and the cumulative grain size distribution. Seven pedo-transfer models were applied by Moene (1990).

In Fig. 6.1.1 results are shown for some of the models.

The main conclusion by Moene was that the results of the comparison of the average retention curves of the different pedo transfer models with the validation curve was not encouraging. In addition he concluded that the pedo transfer models, examined, could not serve as a tool to generate retention data in order to supplement the One-step outflow data.

6.2 <u>A case study of climate change effects</u>

Climate models are still suffering from many incomplete descriptions and parameterizations of the relevant processes. In spite of these deficiencies







Retention curves from model of Cosby et al. (1984), average retention curve (Δ) with range \pm standard deviation (+ and \diamond) and retention curve from validation data set (\Box); topsoil (a) and subsoil (b)



Retention curves from model of Arya and Paris (1981), average retention curve (Δ) with range \pm standard deviation (+ and \diamond) and retention curve from validation data set (D); topseil (a) and subseil (b)

Fig. 6.1.1 Comparison of results of some pedo-transfer models with independently determined retention data for validation.

the models are quite consistent in predicting the tendencies of climate change due to an enhanced greenhouse effect. A doubling of the CO_2 content in the atmosphere would roughly result in a few degrees temperature rise for Western Europe, an increase in rainfall up to 10%, mainly in the winter and an increase in potential evapotranspiration. Although these figures have to be considered as indicative, for future policy they may be important as a base for judgement of effect studies of climate change. One class of effect studies concentrates on the hydrological consequences of a climate change. However, climate models do not produce detailed and accurate information on a future climate, neither in space or time. In fact, for effect studies one needs consistent, future climate scenarios. It means that all the relevant atmospheric inputs for hydrological studies, like rainfall, radiation, temperature, relative humidity, wind velocity etc. have to be statistically quantified by their correct means, variance, covariance and persistency, in order to generate 'realistic' future climatological time series. No such a 'weather generator' is available. Parmet et al. (1991) choose another approach to study the possible hydrological effects due to the indicative changes of the climate for They selected 'Rennes' (France) being an existing Western Europe. meteorological station, which shows from its mean records a fair agreement with the actual Dutch climate, corrected for the mentioned, indicative, figures. Using an existing station safeguards the condition of internal consistency of meteorological data sets.

For a period of eleven years the water balances were calculated for a Dutch meteorological station and 'Rennes'. Calculations were performed by using the transient flow model, SWATRE (Belmans et al. 1983) for daily meteorological inputs.

As one of the results, in Fig. 6.2.1, the cumulative evapotranspiration deficit is shown for the growing season from year to year.



Rennes 2000 Hupsel



The overall impression is an increase in magnitude and frequency of deficits.

7 CONCLUSIONS AND EVALUATION

7.1 <u>Conclusions</u>

Although under each Chapter conclusions have been drawn already, they are shortly summarized below.

- Describing spatial variability of soil hydraulic properties by means of reference curves for $h-\theta$ and $k-\theta$ and a set of scaling factors is a feasible way to do.
- Regionalization of vertical unsaturated flow can be realized by using a stochastic-deterministic modelling approach. However one needs an inexpensive and fast method for estimating soil hydraulic properties.
- The One-step outflow method in combination with inverse modelling fails to produce a unique solution for the hydraulic functions of a soil sample.
- The Multi-step outflow method appears to be a promising alternative.
- In principle the inverse modelling technique can be applied to spatially small and large scale problems to estimate scale-effective hydraulic functions. However, it is still not clear to what extent the validity of these 'effective' functions can be extrapolated beyond the original boundary conditions for which they were derived.
- There is no theoretical evidence why the scaled mean reference functions would behave fairly well as 'effective' functions for a, statistically, homogeneous soil type. Yet, it seems they do.
- Land surface parameterizations in atmospheric models are still poorly validated and should be critically tested and, where needed, improved.
- Testing of land surface parameterization can hardly be done by experimental data on the aimed spatial scale. For the time being an indirect approach seems to be the most feasible way.
- Existing pedo-transfer function models do not yield satisfying results for estimating (a) soil hydraulic function(s).
- From a simple climate change scenario study it appeared that the hydrologic regime in the Netherlands has a tendency to become more critical. However, the study should be considered as being indicative due to many uncertainties in the choice of scenarios.

7.2 Evaluation

In section 1.2 the contribution and main objectives of 'Wageningen' were outlined.

Since the start of the project good progress has been made toward approaches of regionalization of spatially variable unsaturated flow. Scaling in combination with stochastic-deterministic modelling and inverse modelling technique have been explored and tested. Both approaches will be further investigated and extended. This is only possible if such field data are or become available, which are indispensable for making progress on these approaches. In the context of the large scale Hapex or Hapex-like field experiments several data sets on soil hydraulic properties have been realized or will soon be realized. The Multi-step method proves hereby to be a valuable tool.

Finally, joint work on testing and validating large scale land surface parameterizations has been initiated during the course of this project. Not included in this report is a draft paper by Kim et al. (submitted for review) on testing and improving land surface parameterizations by the twostep approach, described in section 1.2. As memorized already in section 5.3, further execution of a joint workplan on this topic is presently underway. It is interesting to note that recently the topic has got a world wide initiative by the PILPS-program (Henderson-Sellers, 1992).

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APPENDIX I Publications, related to the project. They are listed according to the different Chapters.

<u>Chapter 2</u>

- Hopmans, J.W. and J.N.M. Stricker. Stochastic analysis of soil water regime in a watershed. J. of Hydrology 105, 1989, 57-84.
- Hopmans, J.W. and J.N.M. Stricker. Application of scaling techniques at a watershed scale. Proc. of Symp. 'Land qualities in space and time', Wageningen 1989, 181-184.

<u>Chapter 3</u>

- Dam, J.C. van, J.N.M. Stricker and A. Verhoef. A first exploration of the One-Step outflow method. Proc. of the Int. Workshop on Indirect Methods for estimating properties of unsaturated soils. Oct. 1989. Riverside, California. 6 pages. In press.
- Dam, J.C. van, J.N.M. Stricker and P. Droogers. 'From One-Step to Multi-Step'. Determination of soil hydraulic functions by outflow experiments. Report no. 7. Dept. of Hydrology, Soil Physics and Hydraulics, 1990, 40 pag.
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- Dam, J.C., J.N.M. Stricker and P. Droogers. Inverse Method for determining soil hydraulic functions from Multi-Step outflow experiments. Soil Science Soc. Am. J. (under review), 1992b.
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- Kim, C.P., P. Droogers, J.C. van Dam and J.N.M. Stricker. Measurement of soil physical properties at the Castelnau-site of the HAPEX-Mobilhy area. Report, 1991, 14 pages.
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Chapter 4

- Feddes, R.A., G.H. de Rocij, J.C. van Dam, P. Kabat, P. Droogers and J.N.M. Stricker. Estimation of regional effective soil hydraulic parameters by inverse modelling (30 pages). In: Water flow and solute transport in soils: modelling and application. Editors: D. Russo, G. Dagan, 1992, Springer Verlag, in press.
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Chapter 5

- Kim, C.P. Land Surface-Processes in Climate Modelling. A Review. Internal note of the Department, 1991, 21 pages.
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Chapter 6

- Moene, A.F. The addition of retention data derived from Pedo-Transfer functions in One-step outflow optimization. Report no. 11, Dept. of Water Resources, 65 pages, 1990.
- Parmet, B.W.A., J.N.M. Stricker and P.M.M. Warmerdam. Consideration of hydrological effects in the 'Hupselse Beek' catchment by a hypothetical climate change (in Dutch) H₂O, 1991, pag. 602-607, nr. 21.

APPENDIX II Presentations related to the project.

- <u>Dam</u>, J.C. van. The application of inverse modelling to derive model parameters and some possibilities to use effective parameters for regional soil moisture modelling. Dutch Study Group on 'Spatial variability of soil and water'. October 1990.
- Droogers, P., J.C. van Dam and J.N.M. <u>Stricker</u>. Soil physical characterization of a sandy soil in the Hapex-Mobilhy region and its meaning for modelling the soil moisture regime at different scales. EGS-meeting Copenhagen, April 1990.
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