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8. SUMMARY

MODELLING AND MONITORING FOREST EVAPOTRANSPIRATION: BEHAVIOUR, CONCEPTS AND PARAMETERS

Mathematical models are univocal descriptions of our concepts. They represent our perception of the true world. These models are most valuable if confidence is gained in the model concepts and the model parameters. By comparing model results to measurements, model concepts and values of model parameters can be tested. In general, this is called validation. Modellers, however, often claim that a model is validated without any reference to their criteria and neglecting the complex process of gaining confidence.

From a scientific point of view, models can be used to improve the understanding of processes, to extrapolate in time and space or to determine variables, which cannot be measured directly. To achieve these goals, the model behaviour is compared with the system behaviour, e.g. the measurements. The understanding of the processes can be improved by identification of variables and processes that were not or not optimal included in the model concept. The uniqueness of the model parameters must first be determined before the parameter values can be interpreted and linked to system properties. This thesis deals with model concepts and model parameters that describe forest evapotranspiration of a Douglas fir ecosystem.

The energy and water exchange at the earth surface play an important role in climate and climate change research. The major issues in this so-called Soil Vegetation Atmosphere Transfer (SVAT) research are (1) detailed plot scale research and (2) research how to scale these SVAT processes up in time and space. This study deals with detailed plot scale research for both transpiration and evaporation. Attention is paid to confirmation and falsification of different model concepts and to the localisation of information in measurements to obtain better estimates of parameters and to improve the model concepts. All measurements used in this thesis are performed in the Douglas fir stand, on acid sandy soils, Speuld, the Netherlands

Forest transpiration: Concepts and parameters

In chapter 2, three forest transpiration model concepts were evaluated. The first model is based on the leaf cooling and calculated transpiration on basis of the requirement of water for cooling the canopy. Trees are simultaneously warmed by incident solar radiation and cooled by ambient air and by transpiration.

The second model is based on the CO_2 assimilation. If stomata are open, gas exchange of CO_2 and H_2O takes place, which is described at the leaf level. Because CO_2 assimilation is determined by a non-linear function of radiation, the radiation regime in the canopy is modelled with a 3-dimensional light interception model to simulate transpiration at the stand level.

The third model is the so-called 'Single Big Leaf' (SBL) model based on the combined energy and water balance, where the bulk stomatal conductance of the Penman-Monteith equation was described as the products of response functions to several environmental conditions.

All models have different complexities and have different numbers of calibration parameters (ranging from 1 to 6). Model results were compared with half-hourly vapour flux eddy-correlation measurements. The performances of these models showed to be equally good, with $R^2 = 0.777$ to $R^2 = 0.834$, meaning that all concepts were confirmed by the measurements. As a result, a model concept could not be rejected. However, significant discrepancies become apparent when differences between model responses were examined. Main differences between the models were caused by another formulation of vapour pressure deficit and leaf area index (LAI).

In chapter 3 the exchange of CO_2 and H_2O was modelled. In this study CO_2 flux measurements, obtained by 6 gas exchange chambers, were used to identify the parameters of the combined Farquahar/Ball model applied at the leaf level. The highest correlation coefficients between diurnal measured and modelled net photosynthesis was $R^2 = 0.87$ and the lowest $R^2 = 0.61$. These chambers were placed in different trees and at different heights within the canopy. Thereupon, the model STANDFLUX was used to estimate transpiration, CO_2 assimilation and water use efficiency for the total stand. This model integrates the three-dimensional aspects of canopy structure and light interception, one-dimensional vertical stand microclimate and the Farquahar/Ball model. With detailed biomass measurements of needle and branch surface area, the trees were reconstructed and used as input for the STANDFLUX model. Daily deviations between simulated transpiration and measured sapflow were found. To obtain an optimal fit, Ball's model parameter *GFAC* was calibrated. This, however, hardly influenced the assimilation. Clear correlations between *GFAC*, temperature and soil water content were observed, meaning that alternative stomatal models should be used to obtain better model predictions.

Information content of measurements

Nowadays models often contain many parameters of which parameter values are mostly estimated by fitting the model results to measurements. Non-unique parameter values can be found due to the properties of the measurements and the correlation between parameters. A unique parameter set with high accuracy is a prerequisite to understand the values and to use the parameters for extrapolation in time and space. The *P*arameter *I*dentification *M*ethod based on the *L*ocalisation of *I*nformation (*PIMLI*) was developed to assess unique parameter values with high accuracy. *PIMLI* selects measurements where the model sensitivity to one parameter is high while the model sensitivity to the other parameters is low and the confidence interval of the measurement is small.

In a hydrological context, the most important characteristic of the SBL model is the stomatal conductance model. The stomatal conductance is described as a product of response functions to vapour pressure deficit, global radiation, temperature, soil water content and LAI. The model contains many calibration parameters and mathematical formulations of the response functions. In chapter 2, a good fit was found between the SBL model results and the eddy-correlation measurements. Time series of environmental conditions describing forest transpiration contain many periods with coupled conditions and redundant information while other conditions were almost not measured.

In chapter 4, the information content of every measurement for every parameter is calculated with *PIMLI*. Measurements with high information content were selected by using independent measurements of environmental conditions. With these independent criteria, periods were selected that have maximum information to identify the parameters. Measurements that were not selected do not add more information to maximise the parameter accuracy further. It is concluded that identification problems will not disappear with the availability of more measurements. The parameter estimates and the fit error obtained by *PIMLI* are compared with a conventional simplex parameter identification method using the Jack-knife method. In total 100 sub-data sets were drawn from the total data set containing 60 measurements and were used to identify the parameters. With the conventional method, different parameter sets were found due to the properties of the sub-data sets and due to the non-uniqueness. With *PIMLI*, a better fit with smaller parameter accuracies was found. As a result, *PIMLI* identifies unique parameter values with high accuracy by using a limited amount of calibration data.

In chapter 5 the model parameters of a rainfall interception model were identified from throughfall and canopy storage measurements. Throughfall, canopy storage and evaporation processes are all dependent of each other. If parameters are identified from a time series in which all these three processes occur at the same time, than a dependency between the parameters is found. *PIMLI* is used to assess the criteria for selecting measurements at periods in which the parameters and processes are independent. With only these measurements, the uniqueness and accuracy of the parameter estimates were calculated. With throughfall measurements, only the interception fraction could be identified with satisfying accuracy. This fraction is independent to other parameters and processes if storage has not yet reached its saturation point and if evaporation is negligible. The accuracy of the estimated storage capacity parameter remained low (σ_c = 0.55 mm). Best identification was achieved with rain events that are just large enough to saturate the canopy and where evaporation is negligible. The drainage parameter could not be identified from throughfall measurements. The model formulations show that this parameter can only be identified if both the storage capacity and the storage are known. The evaporation amount of the canopy is estimated at the end of a rain event. However, the potential evaporation during rain is very low and the identification of the evaporation parameter is dependent on the uncertainty of the storage capacity parameter. It was found that this parameter could also not be identified.

A much higher accuracy of all parameter estimates was obtained with canopy storage measurements. The accuracy of storage capacity parameter was σ_c = 0.04 mm. Parameters were identified during the independent stages of the wetting and drying cycle. It is shown that the uncertainty in throughfall predictions simulated with these parameter estimates was even lower than the standard deviation of the throughfall measurements. With *PIMLI*, it is shown that specific conditions can be selected to improve the drainage and evaporation functions of the model. In contrast, a normal identification focuses on a mean fit for the total data set and therefore individual deviations are more difficult to find.

Analyses of residuals

After parameter identification, residuals between model results and measurements still remain. Random and systematic measurement errors and model inaccuracies cause these discrepancies. The model inaccuracies are systematic errors due to wrong parameter estimates or due to a wrong model concept. In chapter 6, artificial neural networks (ANNs) were used to analyse the residuals for any systematic relationship that may improve the performance of the SBL model. Several environmental conditions were used as input of the ANNs to analyse the residuals. Only systematic errors with an identifiable physical basis were used to improve the model concept or the parameterisation. ANNs show trends in residuals that were related to both wind speed and wind direction. They were able to localise the source area of the fluxes of the Douglas fir stand within a larger heterogeneous forest without adding a priori knowledge of the forest. By calibrating the model only on this source area, the root mean squared error (RMSE) between the SBL model results and measurements decreased from 26.41 $W\ m^{-2}$ to 21.85 $W\ m^{-2}$. With ANNs, improvements were also found in the shape and parameterisation of the response functions. The remaining residuals do not contain any systematic deviation, which is related to the environmental conditions and can be attributed to the random measurement error of the eddy correlation.