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Transformation of near-surface meteorology in a small scale landscape with forests and arable land

Hutjes, Ronald Wilhelmus Antonius

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III. SUMMARY

The state of the atmospheric surface layer, the bottom 10-100 meters of the atmosphere, is strongly influenced by the earth surface. The local wind field is modified by the presence and structure of vegetation. The availability of water and the physiology of plants determine the partitioning of radiative energy into sensible and latent heat fluxes, and thus also local temperature and humidity fields. In a heterogeneous landscape highly localized microclimates emerge from this reciprocal interaction between atmosphere and earth surface.

Such generally small, however systematic and therefore significant variation in near surface meteorology cannot be neglected by the users of these data: climate researchers, hydrologists, agronomists and wind engineers. Global climatic trends may be obscured by superposition of microclimatic changes. Any quantitative predictions of evaporative losses, crop yields or power yields from wind turbines can be off by many percents when micro climatic variations are not accounted for. The operational use of such models will be greatly facilitated by a method to remove site specific anomalies from observed time series and, if need be, to replace them by anomalies from another site. This thesis reports on the development and feasibility of such a transformation model. The scope is limited to transformation in a hydrometeorological context between arable fields and forest.

The 'bottom-up top-down' concept is basic to the model. It uses the fact that, within a limited range of spatial scales, the horizontal variation in meteorology quickly decreases with height. If it is possible to connect this heterogeneous near surface meteorology with the regionally homogeneous meteorology at greater heights (reference height), then a methodology can be envisioned that entails computation of a regional meteorology from ground observations at one particular site, followed by computation of near surface meteorology at another (hypothetical) site from the same regional meteorology. The simplifications made in a first attempt to create such a model are analyzed in chapter two.

This simple model assumes that the atmosphere is in equilibrium with the surface upto the reference height. Moreover this reference height is set to a constant value of 100 m. Such a model has been tested on data from Thetford forest (SW-Britain). An evapotranspiration model explained 69% of the variance in forest evaporation when using input data observed over the forest. Using data observed over a nearby grassland decreased the explained variance to 48%. Inclusion of the transformation model does not improve this figure. Further analysis revealed that evaporation is strongly radiation driven and not by atmospheric demand. Thus evaporation is determined by a circumstantial shading from clouds, a process which is not accounted for in the transformation model. Another reason for the lack of

performance of the transformation model may be the coarse modelling of heat fluxes over the grassland.

The same model has been further analyzed with the HAPEX-MOBILHY data set (SW France) which includes flux observations above both low crops and forest. The evaluation proceeds by extrapolation of profiles above a number of sites in order to see wether, and if so, how, and at which height profiles above two contrasting sites merge into a common regional value. In this evaluation both assumptions of the model emerge as over-simplifications. Only in a limited number of cases is it justified to model profiles in equilibrium with the surface. In many of the remaining cases advection plays a role. Furthermore, the reference height turns out to be highly variable. Nevertheless, the potential of transformations seems high when both points can be improved in a new model.

Further development of the transformation methodology made use of data gathered in the Sleen Hydrometeorological Experiment on Advection and Regionalisation, which is described in chapters three and four. The project aimed at an enhancement of our knowledge of advective processes around a transition from agricultural land to forest. Therefore, measurements have been made of turbulent momentum and heat fluxes, radiation balances and wind, temperature and humidity profile above a forest and two adjacent arable crops (grass and barley) during 1989-1991. Analysis of (weak) horizontal and vertical atmospheric gradients requires high quality data. An extensive error analysis shows that, using eddy correlation, heat fluxes can be determined within 15% and momentum fluxes within 20%. Both errors are largely stochastic in origin. The systematic component is hard to quantify because it is the product of an a-priori unknown turbulence spectrum and the response function of the sensor used. Temperature and humidity could be determined within 0.2 °C and 0.4 g/kg respectively. Cup anemometers used have been shown to seriously underestimate wind speed close to the forest.

With these data the three distinct microclimates have been described. The relevant processes have been identified i.e. quantified in terms of available (sub-) models. Such models assume local equilibrium. However, at all three sites the energy balance can not be closed with certain wind directions, probably due to advection. Also storage of energy may play a role not accounted for. Effective roughness parameters vary systematically with wind direction. For the forest these show a clear relation with fetch.

Bowen ratio increases in the order barley, grass, forest. Given the respective radiation balances this variation leads to a forest climate being on average slightly warmer and drier than the barley, but slightly colder and wetter than the grass climate. To model energy partitioning the canopy conductance model according to Stewart has been optimized for the forest. For the arable crops fixed crop factors have been determined.

With these data and derived model parameters various variations of a

new transformation model have been tested as described in chapter five. Internal Boundary Layer (IBL) height computed from wind direction dependent fetch serves as variable reference height in these models. The simple equilibrium profile is replaced by a three tier IBL model: an equilibrium profile close to the surface, a regional profile near the top of the IBL and a transition profile in between. The models differ in the way the regional profile is derived. In one model the wind speed at the IBL top is computed from near-surface measurements and interpolated over the transition depth. The other model computes the momentum flux at the IBL top from near surface observations of the standard deviation of horizontal wind speed, and interpolates this flux over the transition layer. In both models heat fluxes are still assumed to be constant over the entire IBL.

The new models, and the first one as well, have been evaluated regarding their ability to transform contrasting near surface meteorology from two sites to a common regional meteorology at reference height. All model versions perform better for wind speed than for temperature and humidity. This probably relates to the much larger contrasts in roughness in this landscape relative to the contrasts in energy partitioning. For wind each model performs best in cases (wind direction) when the actual situation most closely resembles the model situation implicit in its assumptions. This means that for locations with long fetches the local fluxes can be used to model an equilibrium profile upto the top of the IBL. With less optimal fetches, one of the more complex models should be used. For temperature and humidity a relation between wind direction and model performance has not been found.

In chapter six the models developed in the previous chapter are evaluated in the context they have been developed for. An analysis is made of the performance of the models mentioned above, with respect to their ability to predict transpiration and near-surface meteorology over the target vegetation. This has been done to predict forest fluxes and meteorology from observations over the crops, and vice versa, predicting fluxes and meteorology over the crops from observations over the forest.

The study shows that surface fluxes can be modelled from observations over a different surface. Without a correction forest transpiration is underestimated by 10-14% when data gathered over grass or barley are used. The simple transformation model predicts forest transpiration within 5% if the fetch of the target site is sufficiently long. Also humidity (deficit) and to a lesser extent wind speed are well predicted. Predicting crop transpiration from forest meteorology without correction also causes overestimation. In this case, however, it can not be reduced by transformation because radiation dominates the forcing of transpiration of low crops. Predicting temperature and humidity over the low crops in SHEAR requires the more complex model, because of the unfavourable fetch conditions.

In the SHEAR situation atmospheric fluxes are very often the sum of two

terms: advective and surface fluxes. Neither models includes the advective terms for the heat fluxes and as such they can predict only true surface fluxes. This restriction has implications for practical use of these models.

Based on these results a three way approach to transformation is recommended:

a) The simple IBL model may well predict *surface fluxes* over forest from data obtained over a nearby low vegetation. To predict surface fluxes over low crops from data obtained over different surfaces, no transformation is required.

b) To accurately predict scalars over another vegetation the more complex IBL model is required, that allows for non-equilibrium profiles.

c) To predict *atmospheric fluxes* either of the models should be extended to include advection.