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Predicting Near-Surface Meteorological Variations over Different Vegetation Types

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ABSTRACT Meteorological conditions close to a surface are strongly influenced by the properties of the surface itself. As a result, input data for models calculating evaporation of surfaces differing from the measurement site need to be transformed. A transformation scheme proposed by McNaughton & Jarvis is tested on data from HAPEX-MOBILHY. Reference values of wind speed, temperature and absolute humidity at a height at which homogeneity is assumed over the landscape are estimated from observations over agricultural fields. From these reference values near surface conditions over a forest are computed. Wind, temperature and humidity differences between forest and agricultural fields are small in neutral atmospheric conditions but increase with increasing (un)stability. Correlations decrease with increasing distance between sites. The reference height, estimated by comparing the respective profiles from any pair of locations, varies with stability and differs between the three variables. Transformation via a fixed reference height introduces much noise but may be of some use to correct long term averages. Possible improvements are discussed.

INTRODUCTION

Modelling of evaporation from vegetated surfaces is of interest to both the hydrological and meteorological community. From the hydrological point of view evaporation is an important component of the water balance, even more so for tall vegetations due to high interception losses. For meteorologists evaporation determines the partitioning of incoming radiative heat into outgoing sensible and latent heat, one of the more important exchange processes at the earth surface.

Modelling of evaporation has reached a level of sophistication such that for homogeneous areas measurements can be reproduced by simulations with considerable accuracy. Rather detailed models have been developed for evaporation from different vegetation types with data obtained with high temporal resolution just above the vegetation under study (for grass and arable fields see Feddes et al., 1978; for deciduous and evergreen forest see Veen & Dolman, 1989). Such data are relatively rare. The potential use of such models by agriculturalists, foresters or water managers, would be greatly facilitated if standard meteorological data could be used as input. However, measured at screen height these data are strongly influenced by the underlying surface. When used as input in an evaporation model for a different vegetation type this may lead to significant errors: i.e. using grassland data to simulate forest evaporation may result in errors of 25-37% in dry and wet conditions respectively (McNaughton & Jarvis, 1984; Pearce & Gash, 1980). Therefore, a transformation scheme to correct meteorological data for near-surface effects is needed.

Also, an effective transformation scheme might be of great use to, and benefit itself from, studies concerned with the problem of regionalisation. Main objective of theoretical and experimental research in this field is the integration of meteorological point measurements and local surface parameters to effective regional values, for use in i.e. General Circulation Models (GCM) (Shuttleworth, 1988). Mapping meteorological variations in the Surface Layer in relation to the heterogeneity of a landscape and the structure of the Mixed Layer above is done in extensive observation programs like HAPEX-MOBILHY and ISLSCP-FIFE (André et al., 1988; Becker et al., 1988).

The present paper presents a study on assumptions and effectiveness of the transformation scheme proposed by McNaughton & Jarvis (1984), using data from HAPEX-MOBILHY.

THE TRANSFORMATION SCHEME

The transformation scheme proposed by McNaughton & Jarvis converses near-surface measurements of wind (u), temperature (θ) and (absolute) humidity (q) to regional reference values which are assumed to exist at a certain height. These reference values can be used to compute near-surface values over any other vegetation type in the vicinity of the measurement site.

Given surface fluxes of momentum ($u'w'$), sensible (H) and latent (E) heat, and assuming constancy of fluxes with height, the surface values of u, θ and q can be extrapolated to a reference height using flux-profile relationships. The assumption of constant fluxes with height limits extrapolation from the surface up to the top of the Surface Layer (SL, also named Constant Flux Layer), which is generally considered to occupy the bottom 10% of the Planetary Boundary Layer (PBL). At the reference height (the top of the SL or bottom of the Mixed Layer, ML) homogeneity of u, θ and q is assumed over a landscape. Within a homogeneous weather system, this assumption limits the scale of surface heterogeneities to about 10 km. Larger fetches may significantly affect the values of especially θ and q in the ML (McNaughton & Jarvis, 1984). Then, given the fluxes over any other vegetation type, again assuming constancy of fluxes from the reference level down to the surface (neglecting advection), the surface values of u, θ and q can be computed.

When used to compute fluxes over a certain vegetation from standard meteorological data, fluxes at both the meteorological site and the site under study have to be parameterised. At the meteorological site fluxes can be estimated from measurements of u, θ and q, deriving $u'w'$ from an estimate of roughness lenghth and zeroplane displacement, using the Penman-Monteith equation for E with some parameterisation for aerodynamic and surface conductances, and computing H by closing the energy balance. At the second site these equations have to be solved iteratively since both fluxes and near-surface values of u, θ and q are unknown.

METHODS

The HAPEX-MOBILHY data base is used to test the transformation scheme. Data from the special observation period (SOP) of six sites, five over arable fields, one over forest, are used (Table 1). Instrumentation differed between forest and other sites. Over the forest fluxes were measured using eddy correlation techniques with 'Hydra' instrumentation (Gash et al., 1989), over the arable fields profile-budget methods were employed with 'SAMER' instrumentation (Bessemoulin et al., 1987). All data were converted to one-hour averages and missing data, where possible, were replaced by interpolation or by closing the energy balance. Bad quality data, as indicated in the original files, were omited from analyses. In all analyses three classes of atmospheric stability are distinguished: unstable, $\zeta < -0.03$; near neutral, $-0.03 \leq \zeta \leq 0.03$; stable, $\zeta > 0.03$ (ζ is the quotient of height over the zeroplane and Monin-Obukhov length). The quality assesment left few data from stable conditions over arable fields. When we speak of 'pairs of sites' in this paper, we always mean the forest site paired to one of the arable field sites.

TABLE 1 Site description HAPEX-MOBILHY.

no	name	dist. km	alt. m	vegetation	height cm	irr.
1	Lubbon 1	5	146	oats	71-149	no
2	Casteljal.	31	131	maize	5-135	yes
4	Courrensan	39	148	wheat	62-82	no
5	Lubbon 2	5	146	maize	12-221	yes
12	Lagrange	11	152	maize	3-67	yes
	Estampon	-	146	pine	2030	no

dist. distance to forest site
alt. altitude (amsl)
height vegetation height on 20-05 and 10-07 1986 respectively
irr. irrigation

First, we establish the errors to be corrected for by the transformation scheme. Since we expect the largest differences between low and high vegetations, u, θ and q of five stations over arable fields are compared with those measured over a pine forest.

Then, an estimate of the best reference height is made by calculating average convergence heights for u, θ and q. The convergence height (h_c) is defined as the height at which the difference between extrapolated u, θ or q from any pair of locations reaches a minimum (not necessarily zero !). Near surface measurements of u, θ and q are extrapolated up to 225 m, the supposed maximum height of the SL (10% of a warm day PBL-depth). The profiles are corrected for stability

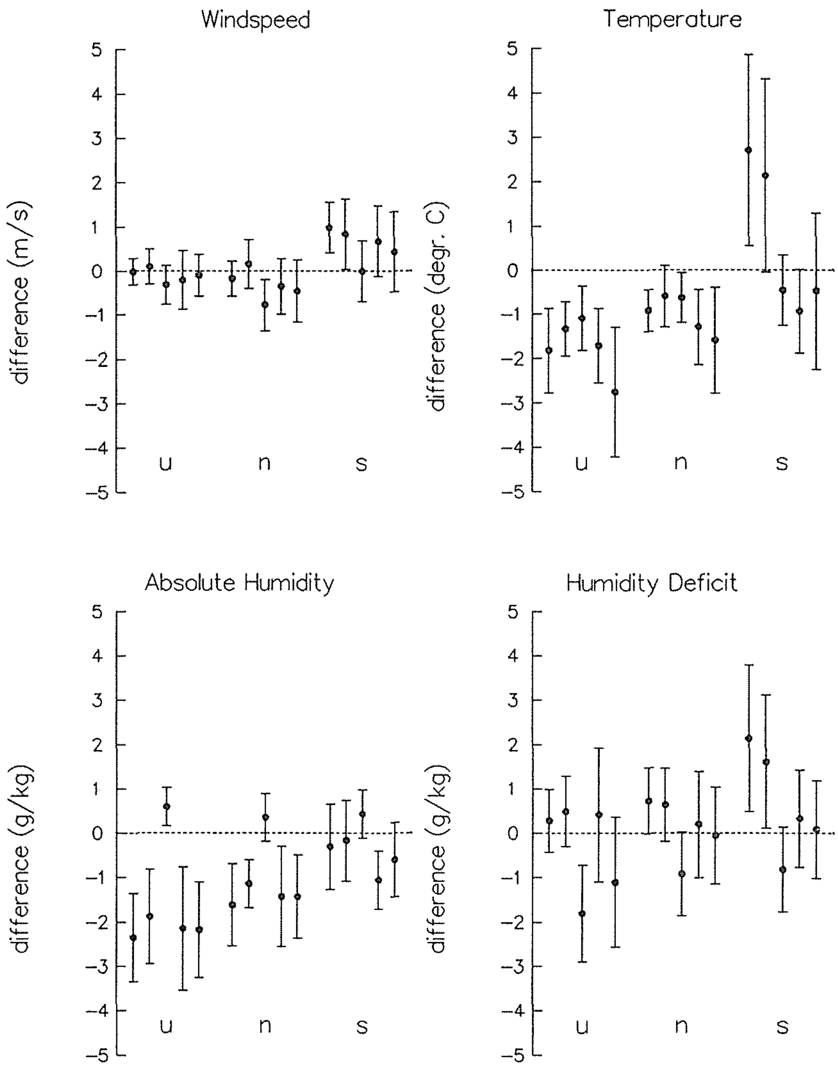

FIG. 1 Average differences in surface meteorology. Difference = observation forest - observation arable field. Clustered per stability class; unstable; near neutral; stable. Within clusters, differences between forest and respectively site 1, 5, 12, 2, 4.

effects using 'universal' flux-profile relations with parameters from Högström (1988).

Finally, transformation of u, θ and q from low vegetation to forest is tested via a fixed or variable reference height. Therefore, we compare parameters of the regressions of data obtained over arable fields, transformed or not, on data obtained over forest.

RESULTS

Average differences between any pair of sites in the three stability classes are plotted in Figure 1. It shows that wind speed differences are rather small, but increase under stable conditions. θ and q differences are smallest in neutral conditions, larger in unstable conditions and very variable for the different sites in stable conditions. Sites 1 and 5 are colder and wetter than the forest in stable conditions. This might indicate gap-effects since both sites are in fact large clearings inside a forest area. However, note that only a limited number of observations under stable conditions are available. The exceptional humidity status of site 12 might result from very poor plant cover during SOP. Correlations between measurements at any pair of sites are invariably very high in neutral conditions, and high but significantly decreasing with distance in conditions diverging from neutral, the decrease getting stronger in the order θ, q and u (not shown).

Extrapolation of measured profiles proved very tricky, especially those over the arable fields. In 25–77% of the hours, mostly very unstable, one of the two profiles of each pair of sites of either u, θ or q, cannot be extrapolated realistically (Table 1). For the remaining cases we expect the profiles over any pair of sites to merge at some height. Primarily two qualitatively different forms of merging do occur. (a) Profiles merge more or less asymptotically and both profiles seem to be in perfect equilibrium with the underlying surface over a considerable part of the SL, Figure 2a. Of these asymptotically merging profiles 20–50% does not merge completely within 225 m.

(b) Profiles converge or even cross each other at a limited height to diverge again higher up. This means that one or both of the profiles is in equilibrium with the surface over a limited height only end in reality will show a transition around that height. This may be caused by advection, due to limited fetches. In most of these cases h_c is at, or slightly above the instrument height over the forest (26 m), Figure 2b.

Nearly all realistic wind profiles merge asymptotically. However, many of the paired temperature and humidity profiles converge in the way shown in Figure 2b.

Average h_c for u, θ and q for any pair of sites under different

TABLE 2 Frequency of occurence (in % of observed hours) of the different convergence situations.

	Convergence situation (see text):		
variable:	no realistic profiles	symptotic converg.	discont. onverg.
windspeed	58	39	3
temperature	35	46	19
humidity	45	27	28

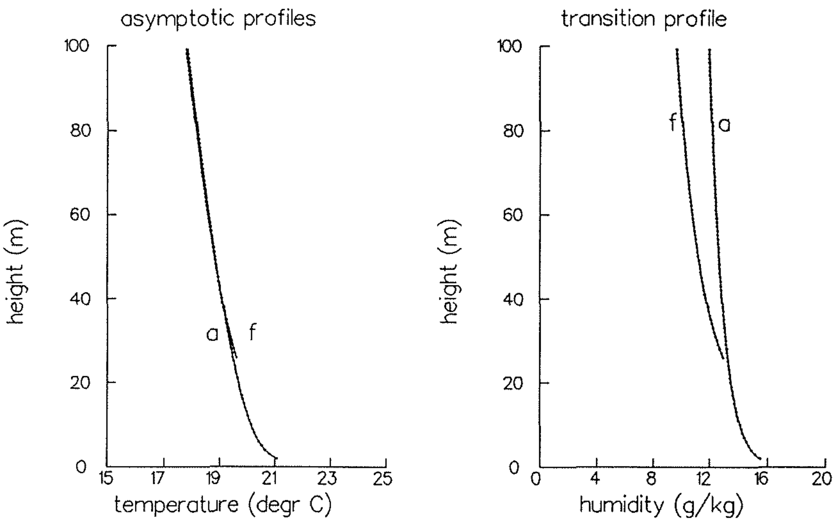

FIG. 2 Possible convergence situation; see text for explanation; arable field; forest.

atmospheric conditions are shown in Figure 3. Only those cases are included with $26 \leq h_c < 225$ m. The variability of h_c is very large. Differences between stability classes are rather small, and, except for wind speed in stable conditions, not significant. The convergence height for u averages 113 m under neutral conditions, is slightly lower in unstable conditions, but significantly lower in stable conditions. The convergence height for θ and q is lower than h_c for u in unstable to neutral conditions but higher in stable conditions. There is no correlation between inter site distance and h_c.

In its simplest form transformation according McNaughton & Jarvis (1984) uses a fixed reference height of which the exact value is assumed to be not important since profiles at larger heights are steep. This assumption is tested by transforming u, θ and q from arable fields to forest via a number of fixed reference heights: 26, 50, 100 and 200 m. In table 3 the results of regressions of observed and transformed data from arable fields on forest data are given. In case of perfect transformation the regression coefficient will approach one, and the constant and residual mean squares (RMS) will approach zero. For operational use these parameters need to be closer to the ideal situation than the results of the regression of not transformed data on forest data. The parameters are given only for the transformation via that reference-height that gives the best results.

Table 3 shows that transformation via a fixed reference height is far from perfect. For u , θ and q transformation via the 50 m (or occasionally 100 m) reference level gives best results; transformation via other reference heights performs considerably worse. However, transforming u seems useless: coefficients differ even more from one, constants are marginally improved and RMS' always increase. Transformation of temperature and humidity is more promising: coefficients are closer to one for most sites, constants decrease and for some sites even rather dramatically, but RMS' remain more or less the same. Distance

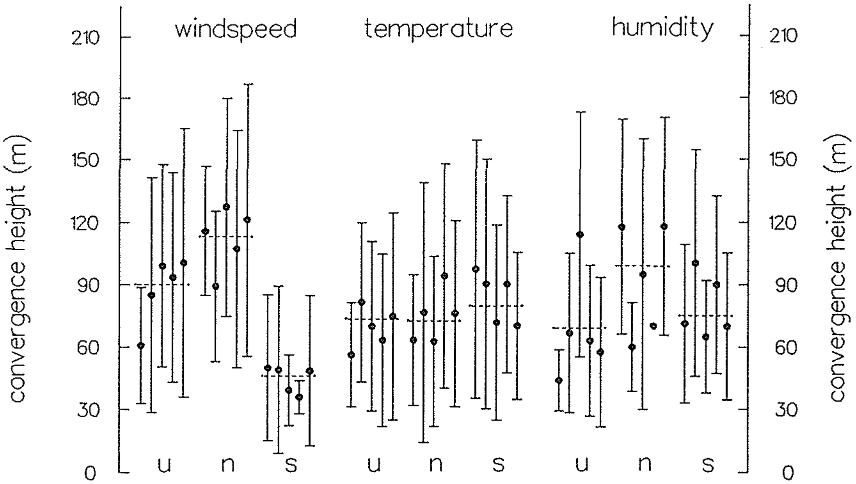

FIG. 3 Average convergence heights of u, θ and q. Clustered per stability class. Within clusters h_c from paired profiles of forest and respectively field 1, 5, 12, 2, 4. Broken lines indicate averages over all pairs.

between sites does not seem to affect transformation, implying a rather homogeneous PBL over upto 40 km.

Of course, a variable reference height, using the convergence height as determined for u, θ or q for each hour, gives the best results. Wind speed can be transformed nearly perfectly, and θ and q can be corrected in a useful way.

DISCUSSION

Much can be said about the differences of u, θ and q between forest and arable fields in different atmospheric conditions. In the context of correcting such differences with the McNaughton and Jarvis approach we only comment on the exceptional temperature and humidity deficit differences between forest and fields 1 and 5 under stable conditions. We think these may be the result of 'gap-effects'. Both sites are in large clearings in a predominantly forested area. This topographical situation may enhance the decoupling of the SL from the rest of the PBL in already stable conditions. This may lead to much lower temperatures and higher humidities, which are no longer coupled to those measured over surrounding vegetations.

The large number of unrealistic profiles (Table 2) after extrapolation are likely to be caused by relatively large measurement errors of u_*, H and E by the SAMER instrumentation in free convection situations combined with the sensitivity of the non-lineair flux-profile equations. Profiles calculated over forest might not be correct, due to uncertain ties regarding the flux-profile relations over rough surfaces. Deviations from standard relations are largest for θ and q, and increase with deviation from neutral stability (Fazu & Schwerdtfeger, 1989).

The occurrence of transitory profiles (a pair of profiles converge at a limited altitude, above which they diverge again; so one or both

TABLE 3 Results of the transformation of u, θ and q via fixed or variable reference heights. Given are the parameters of the regression of observed data over arable fields (S_0) on observed forest data (F), and data from arable fields transformed to over forest, via either fixed (T_f: 50 m reference height) or variable (T_v) reference heights, on observed forest data.

	Coefficient			Constant			Residual Mean Squares		
F vs	S_0	T_f	T_v	S_0	T_f	T_v	S_0	T_f	T_v
Windspeed									
site 1	0.90	1.13	1.05	-0.69	0.60	-0.08	0.39	3.35	0.01
site 5	0.97	1.13	1.00	-0.59	0.41	-0.00	0.33	2.52	0.04
site 12	1.23	1.20	1.05	-0.32	0.43	-0.04	0.24	0.83	0.06
site 2	1.19	1.14	1.04	-0.94	0.67	-0.05	0.27	2.31	0.04
site 4	0.93	1.21	1.01	-0.66	0.18	-0.03	0.31	1.00	0.06
Temperature									
site 1	0.94	1.06	1.00	-0.79	-0.55	-0.34	8.27	5.19	1.28
site 5	1.11	0.98	1.02	-1.61	0.34	-0.41	1.51	1.43	0.54
site 12	1.07	0.97	0.97	-0.54	0.33	0.46	0.62	1.12	0.29
site 2	1.00	0.95	0.96	1.37	1.06	1.23	1.02	1.04	0.81
site 4	1.14	0.95	0.89	-1.12	0.66	2.32	2.18	1.24	1.15
Absolute humidity									
site 1	1.07	1.09	1.10	0.33	-0.50	0.05	1.17	1.86	1.23
site 5	1.24	1.00	0.96	-0.72	-0.33	0.55	1.38	1.06	0.88
site 12	0.96	1.03	0.99	0.00	-0.30	-0.05	0.19	0.43	0.09
site 2	0.93	0.99	1.02	2.26	-0.11	-0.17	0.42	0.64	0.76
site 4	0.91	1.06	1.00	2.19	-0.37	1.05	0.61	0.89	1.32

extrapolations are limited to that height) undermines the basic assumption of the McNaughton and Jarvis scheme that profiles in the SL are fully adapted to the local surface. In a patchy landscape, fluxes measured with limited fetch can't be expected to be constant over the entire SL, due to advection. Downwind of each surface discontinuity an internal boundary layer (IBL) developes in which profiles are adapted to the new surface conditions. Above the IBL and a transition zone profiles are similar to those upwind of the surface transition. From Rawinsonde observations near fields 1 and 5 Parlange and Brutsaert (1989) deduced a regional wind profile at larger heights (> 86 m) with a roughness length of 1.2 m and a zeroplane displacement of 6 m. Clearly forest surface characteristics determine profiles at greater heights whereas near the ground profiles are adapted to the characteristics of site 1 or 5.

Average h_c for u is 60–100 m in unstable and 90–130 m in neutral conditions, which is in the range (86±22 - 160±38 m) in which a regional wind profile is observed by Parlange & Brutsaert (1989). The lower h_c in unstable situations reflects stronger mixing in such conditions. The very low h_c in stable conditions implies a very shallow IBL. Convergence heights for θ and q on the average are lower than for u, and show less variation with stability. This might reflect the smaller capacity of air for momentum relatively to the capacity for heat and moisture. Therefore, surface transitions affect profiles of u to greater heights than profiles of θ or q.

Transformation via fixed reference heights seems to be of limited use in a heterogenous landscape. If the RMS of the regression of transformed field data on forest data is smaller than the RMS of the regression of observed field data on forest data, and if the coefficient is closer to one and the constant smaller, then McNaughton and Jarvis transformation is better than simple lineair transformation using the regression parameters, as is the case for temperature. If the RMS is not too much larger, but the coefficient is closer to one and the constant is smaller, as is the case for humidity, then simple lineair correction might do the job just as well, since only averages can be corrected, not individual observations. In that case McNaughton and Jarvis transformation might provide the parameters.

Obviously, transformation via variable reference heights performs best. Wind speed can be transformed almost perfect given the right reference height. A similar result was obtained by Van Wijk et al. (1990); transforming wind data from off- to on-shore using a parameterised IBL height as reference level worked much better than using a fixed reference level. Sempreviva et al. (1990) improved the transformation even further with a formulation for a transition layer between the IBL and the rest of the SL.

Transforming θ and q via variable reference heights only reduces the RMS compared to transformation via a fixed reference height. The other parameters are not improved. One reason is, in our analysis, that more often than for wind speed convergence of computed profiles is not complete. We are not aware of other studies on transformation of θ or q. A problem in this respect may be the fact that as yet very few models are available for thermal IBL's (the IBL downwind of a transition in surface temperature and/or heat flux).

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