10.2 COMPARISON OF SCALAR ROUGHNESS LENGTHS MEASURED AT AN URBAN SITE AND TWO RURAL SITES

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1. Introduction

Results are presented of scalar roughness lengths calculated from measurements at an urban site, a flat rural site and a hilly rural site. The urban and flat rural measurements were taken with instrumented masts, and the hilly rural measurements with turbulence probes flown on a tethered balloon, as well as ground instruments.

2. Urban and flat-rural mast experiments

The results presented here are taken from two sets of data, the first from a month-long experiment at an urban site in 2000 (Birmingham UK, site described by Rooney 2001) and the second from a reasonably flat rural site (the Met Office Field Site at Cardington UK).

Both sets of results are based on measurements made at ground level and at the top of masts. The ground level measurements are of surface temperature measured by both conventional and IR thermometry. The elevated measurements are of all wind components, temperature and humidity. A sonic anemometer and humicap hygrometer were deployed at both sites at 45m, and a sonic anemometer and OPHIR infra-red hygrometer were also deployed at 10m at the flat rural site only. Turbulent fluxes were obtained by correlation in the usual way, heat flux coming from the anemometer sound-speed measurement. Comparison of both sets of moisture fluxes at the flat rural site have shown that the humicap is capable of resolving the moisture variation sufficiently at this elevation to make moisture flux measurements.

2.1 Calculation of scalar roughness lengths

The scalar roughness length , z_{0S}, appears in the MO scaling formulae for scalar profiles,

$$S(z)-S_0=\frac{S*}{k}\left[\ln\left(\frac{z-\delta_S}{z_{0S}}\right)-\Psi_h\left(\frac{z-\delta_S}{L}\right)\right] \quad . \tag{1}$$

Equation (1) is the equation of a plane, $\mathbf{x}.\mathbf{n}=d$, in the variables

$$x_1=S(z)+\frac{S*}{k}\Psi_h\;,x_2=S*\;,\;x_3=S_0\;. \tag{2}$$

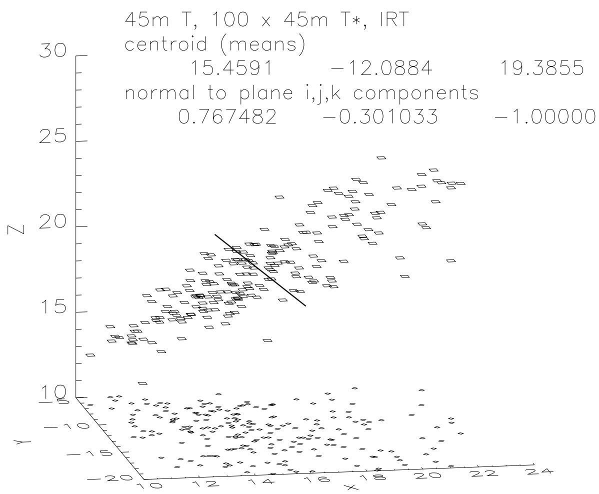

Figure 1: Example plane fit for Birmingham 45m θ, $\theta*$, θ_0. 'Shadows' of points on XY-plane are shown as small diamonds.

such that

$$n_2/n_1=-\frac{1}{k}\ln\left(\frac{z-\delta_S}{z_{0S}}\right) \quad . \tag{3}$$

The method used *for the mast experiments* is to fit a plane by least-squares to the entire dataset, to obtain an optimum value of z_0T or z_0q which is representative of the entire experiment, e.g. Figure 1.

3. Hilly-rural balloon experiment

The hilly rural experiment took place in Wales (Ordnance Survey reference SN922369). Turbulence probes (Lapworth & Mason 1988) and an IR thermometer were attached to the cable of a tethered balloon, flown from a site on a ridge orientated roughly north-south. The vertical valley-to-ridge lengthscale was approximately 100m and the orographic horizontal wavelength was approximately 2km. The region is covered in grass, bracken and some trees, and the balloon site was in an area of semi-marsh covered with grass. Local surface humidity measurements were also made.

3.1 Calculation of scalar roughness lengths

For the balloon experiments, assuming horizontal homogeneity and no horizontal scalar transport, the local temporal rate of change of concentration of a

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scalar, S, is related to the vertical divergence of the scalar flux,

$$\frac{\partial \overline{S}}{\partial t} = -\frac{\partial \overline{(w'S')}}{\partial z} \ . \qquad (4)$$

$\partial \overline{S}/\partial t$ was measured by probes within the boundary layer. Using (4) to determine the local vertical flux gradient, measuring the local scalar flux, and assuming the vertical flux gradient to be constant within the boundary layer (a linear flux profile), an estimate of the surface scalar flux, $\overline{(w'S')}_s$ was obtained (Figure 2). $u*$ was obtained by extrapolating the measured values to the surface (Figure 3). The value of $S* = -\overline{w'S'}_s/u*$ was then used to calculate the scalar roughness length, z_{0S} from (1), the final value being an average over all probes. (The surface $z = 0$ is taken as the mid valley-ridge height.)

This method was used with the observations of both potential temperature, θ, and specific humidity, q, to obtain estimates of z_{0T} and z_{0q}.

4. Discussion

The measured values are tabulated below.

It has been observed in simulations that scalar roughness lengths over complex terrain are smaller than those over flat terrain (Wood & Mason 1991). Concentrating on the IR surface temperature measurements, there does not appear to be a large difference in z_{0T} for the flat-rural/hilly-rural comparison, however there is a difference in magnitude for the flat-rural/urban comparison, possibly because of the increase in $u*$ in the urban environment reducing $S*$ (the reduction in $\sigma_w/u*$ has been noted by Rooney 2000).

For the flat-rural case $q_{\mathsf{sat}}(\theta_0)$ was used for q_0 so these results are a lower bound on z_{0q}. However, this method did not give meaningful results in the urban case, presumably because q_0 is not sufficiently homogeneous. The values of z_{0q} in the hilly-rural case are much smaller than the z_{0T} values, which may reflect the local vs. area-averaged methods of obtaining the surface scalar values.

5. References

Lapworth, A.J. & Mason, P.J. 1988 *J. Atmos. Ocean Tech.*, **5**, 699–714

Rooney, G.G. 2001 *Boundary-Layer Met.*, **100**, 469–486

Wood, N. & Mason, P.J. 1991 *Q.J.Roy. Met. Soc.*, **117**, 1025–1056

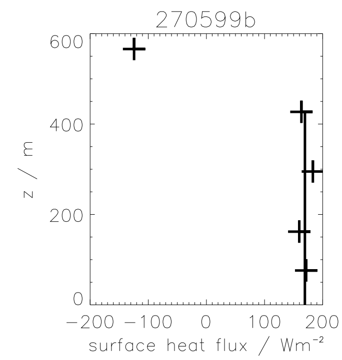

Figure 2: Surface heat flux measurements as extrapolated from probes at different heights along the balloon cable

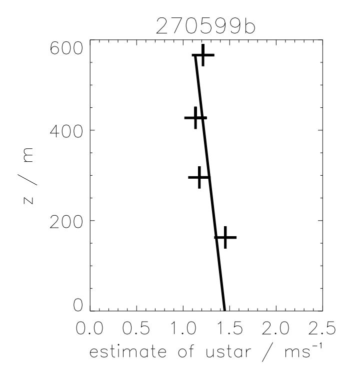

Figure 3: $u*$ measured by probes at different heights along the balloon cable

surface type and surface measurement	z_{0T} (m)	z_{0q} (m)	notes
flat rural surface, IRT	1.16×10^{-3}	2.50×10^{-6}	**45m**, $q_0 = q_{\mathsf{sat}}$(IRT)
flat rural surface, IRT	7.01×10^{-3}	1.02×10^{-5}	**10m**, $q_0 = q_{\mathsf{sat}}$(IRT)
flat rural surface, grass T	1.85×10^{-1}	2.59×10^{-4}	**45m**, $q_0 = q_{\mathsf{sat}}$(grass T)
flat rural surface, grass T	3.12×10^{-1}	5.41×10^{-4}	**10m**, $q_0 = q_{\mathsf{sat}}$(grass T)
urban surface, IRT	6.14×10^{-6}	n/a	
urban surface, concrete T	2.40×10^{-2}	n/a	
hilly rural surface, IRT and humicap q **25/5/99**	1.38×10^{-3}	8.4×10^{-8} 1.7×10^{-13}	q_0 at ridge top q_0 at valley bottom
hilly rural surface, IRT and humicap q **27/5/99**	1.10×10^{-4}	1.4×10^{-10} 3.0×10^{-24}	q_0 at ridge top q_0 at valley bottom