# 2.3 THE APPLICABILITY OF THE SCINTILLATION METHOD OVER HETEROGENEOUS AREAS

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## 1. INTRODUCTION

Surface fluxes at a scale of several kilometers are required in many meteorological and hydrological studies. The scintillation method is one of the few methods that can provide fluxes at these scales (1-10km). Since usually the earth's surface is heterogeneous at these scales and the scintillation method is based on the Monin-Obukhov Similarity Theory (MOST) the question arises whether this technique is applicable. In order to test the scintillation method over an inhomogeneous area an experiment was carried out in Flevoland (The Netherlands), using two different types of scintillometers.

## 2. SCINTILLATION THEORY

A scintillometer consists of a transmitter and a receiver unit and measures intensity fluctuations. By emitting a beam of light with a specific wavelength ($\lambda$) through the atmosphere over a horizontal path intensity fluctuations ($\sigma_{lnI}^2$) can be observed at the receiver side. The intensity fluctuations are caused by turbulent temperature and humidity fluctuations and can be expressed as the structure parameter of the refractive index of air ($C_n^2$). It is known that in the visible to near-infrared wavelength region scintillations are primarily caused by temperature fluctuations. At radio wavelengths humidity fluctuations also contribute to $C_n^2$.

The first scintillometer used in this experiment uses a wavelength of 940nm, i.e. $C_n^2$ is related to $C_T^2$. By applying MOST the sensible heat flux ($H$) can be derived. The second scintillometer measures scintillations at a wavelength of 11mm, i.e. humidity fluctuations ($C_q^2$) contribute to the $C_n^2$-signal. By combining these two different scintillometers both the sensible and latent heat ($L_vE$) flux can be derived following MOST.

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## 3. ASPECTS OF SURFACE HETEROGENEITY

In **Figure 1** a schematic diagram is shown of the various layers over a heterogeneous landscape. As the air flows from one patch to another patch an internal boundary layer (IBL) develops. It is expected that the top of each IBL becomes diffuse as the flow encounters new surface conditions. At a certain height above the surface it is expected that the signatures of the patches tend to merge due to turbulent mixing. This height is often called the blending height ($z_b$). In general this height can be seen as a level where the influence of the patches or surface perturbations gradually decay. The blending height primarily depends on the horizontal scale of the inhomogeneities $L_h$ (Wood and Mason, 1991)

$$z_b \approx 2\left(\frac{u_*}{U}\right)^2 L_h$$

where $u_*$ the friction velocity and $U$ the wind speed at height $z_b$. In this study we will adopt the model proposed by Wood and Mason (1991) as a working hypothesis.

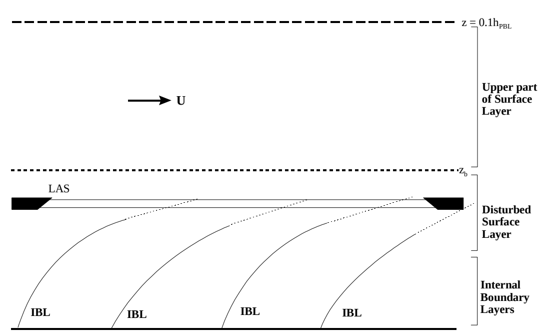


Figure 1: Schematic diagram of the various layers over a heterogeneous flat landscape, showing the heights of the top of the internal boundary layers, the top of the surface layer and the blending height.

For type A landscapes the horizontal scales of the inhomogeneities are much smaller than 10km. In this case primarily the lower part of the surface layer (SL) is affected, whereas the planetary boundary layer (PBL) 'feels' a single surface (De Bruin, 1988). The Flevoland area can be considered as type A landscape ($L_h$ < 10km).

When a scintillometer is located below the blending height the situation is more complicated. The scintillometer will 'see' the fluxes from the individual patches (**Figure 1**). As a result turbulence is not in equilibrium with the local vertical gradients or structure parameters and MOST might be violated.

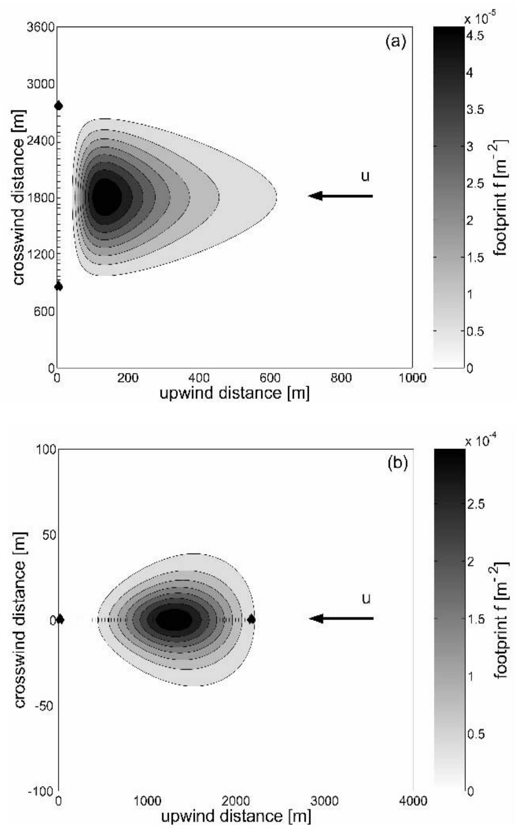


Figure 2: The footprint of a scintillometer ($z/L_{ob}$ = -0.23, $\sigma_v$ = 0.5ms$^{-1}$ and L = 2.2km) for perpendicular (a) and parallel (b) wind directions to the path of the LAS.

Below the blending height a portion of the surface upstream, known as the source area (SA), influences the measurements. A useful tool to estimate the source area for fluxes is a footprint function. The footprint function (*f*) relates the measured flux $F(x,y,z_m)$ to the spatial distribution of surface fluxes $F_0(x',y',0)$ (Horst and Weil, 1992)

$$F(x,y,z_m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} F_0(x',y') f(x-x', y-y', zm)\,dx'dy'$$

For a scintillometer the footprint has to be combined with the spatial weighting function of the LAS (which is bell-shaped) in order to determine its source area. In **Figure 2** the footprint is shown for a LAS where the wind direction is perpendicular (a) and parallel (b) to the path. For both examples the atmospheric conditions are identical. It is clearly noticeable that the SA is larger when the wind direction is perpendicular to its path than for parallel circumstances.

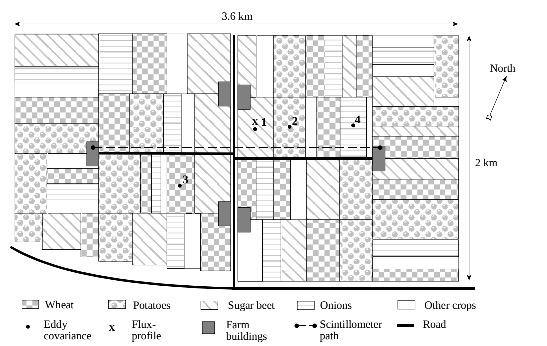


Figure 3: A plan of the Flevoland area showing the vegetable plots, the eddy covariance locations (numbered circles) and the beam of the scintillometers (dashed line).

## 4. EXPERIMENT

In the Flevoland area four crops were grown namely, sugar beet, potatoes, wheat and onions. Each crop covered 25% of the area independent of the wind direction (i.e. isotropic conditions). The area we focus on is depicted in **Figure 3**, further denoted as area A. Important to note is the rectangular shape of most fields.

The scintillometers, two optical (LAS1 and LAS2) and a radio wave scintillometer (RWS), were mounted in two suitable wind turbines at a height of 11.6m (LAS1 and RWS) and 20.4m (LAS2) (**Figure 3**). The path length was 2.2km. In total four eddy covariance instruments were installed to provide independent surface flux ($H$, $L_vE$ and $\tau$) measurements of each crop.

From the eddy covariance measurements it was found that the spatial variations in surface roughness were very small. In the context of MOST, the heterogeneity was primarily caused by spatial variations in thermal properties, i.e. the contrasting fluxes of $H$ (and $L_vE$), especially for wheat (**Figure 4**).

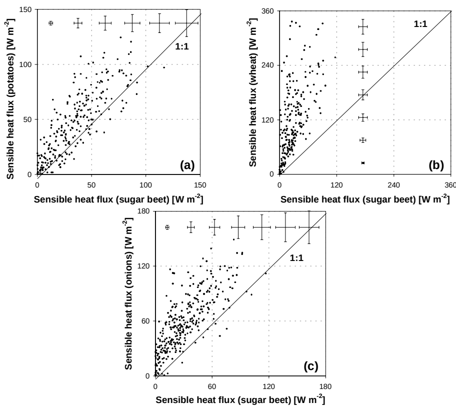


Figure 4: Comparison of 30-minute average fluxes of sensible heat measured over the four crops.

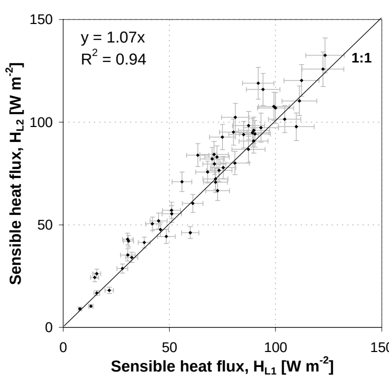


Figure 5: Comparison of sensible heat fluxes derived from the lower LAS ($H_{L1}$) and the upper LAS ($H_{L2}$).

## 5. RESULTS

The sensible heat fluxes derived from both LAS devices ($H_{L1}$: LAS at 11.6m, $H_{L2}$: LAS at 20.4m) were compared with the area averaged fluxes $H_A$, which were derived as follows

$$H_A = \sum_i f_i H_i$$

where $f_i$ is the fractional cover of each crop $i$ in area A. Inter comparison of the scintillometer fluxes with each other (**Figure 5**) and with the area averaged fluxes of area A ($H_{L1}$ and $H_A$, **Figure 6**) revealed that lower LAS gave slightly lower fluxes.

Due to the rectangular shape of most fields in the area (500 x 250m) we found for parallel wind directions (to the path of the scintillometers) that the signatures of the patches start to blend at a height of approximately 5m, which is well below the measurement height of both scintillometers (following the model proposed by Wood and Mason, 1991). For the other wind directions the blending height varied between 9m and 14m. Which suggests that for these wind conditions the lower LAS is situated below the blending height.

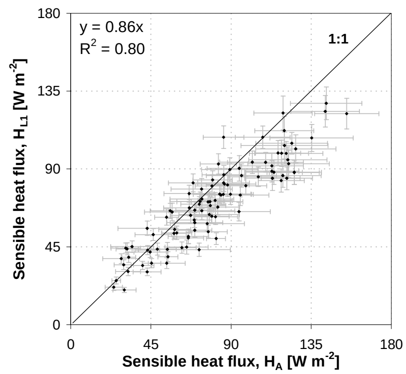


Figure 6: Comparison of the sensible heat flux derived from the lower LAS ($H_{L1}$) plotted against the area averaged fluxes ($H_A$).

To conduct a footprint analysis to estimate the source area of the lower LAS we divided area A in 8 wind direction sectors (each $45^o$). By combining the LAS footprint (for each sector) with a land cover map of area A, the relative contribution (i.e. $f_i$) of each crop could be estimated and thus finally the area averaged flux of the source area. Arranging of the area averaged fluxes of area A ($H_A$) and the source areas ($H_{SA}$) based on the wind direction resulted in a better 1:1 agreement with the fluxes of the lower LAS (**Figure 7**).

In **Figure 8** the latent heat fluxes from the combined LAS-RWS system are compared with the area averaged fluxes thereby following the same procedure as for the lower LAS in **Figure 7**. It can be seen that the evaporation fluxes from the LAS-RWS are slightly higher than the aggregated eddy covariance fluxes. However an analysis of the energy balance closure revealed a gap of almost 20% for the aggregated eddy covariance fluxes while the scintillometer fluxes show a closure of 95%.

Although the overall effect of the footprint method was less noticeable for the evaporation fluxes (due to the relative wet conditions) the results show that reliable fluxes can be derived from the LAS-RWS combination.

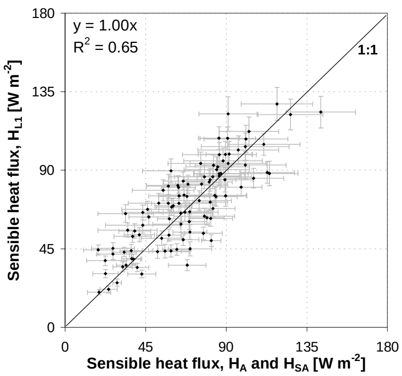


Figure 7: Comparison of 30-minute fluxes of sensible heat derived from LAS1 ($H_{L1}$) and the area averaged heat flux for area A ($H_A$) and the source area ($H_{SA}$).

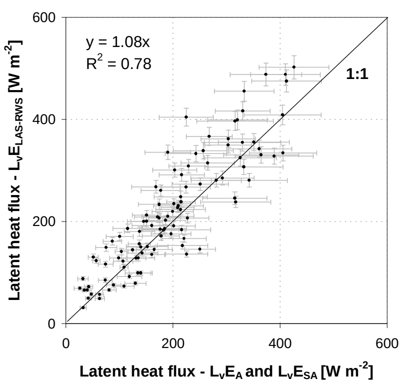


Figure 8: The latent heat flux determined with the LAS-RWS ($L_vE_{LAS-RWS}$) system versus the area averaged eddy covariance measurements ($H_A$ & $H_{SA}$).

## 6. CONCLUSIONS

We have demonstrated that area averaged fluxes of sensible and latent heat can be derived from scintillometers, which are installed over a heterogeneous landscape of type A. The results also show that reliable fluxes can be obtained when the instruments are located below the blending height. This suggests that the violation the MOST relationship ($C_T^2$ – $H$) is small. The slight underestimation of the lower LAS could be assessed using a blending height and footprint model. After accounting for the spatial distribution of the surface fluxes in the source area of the LAS the results agreed well. Also note that these are one of the first results of a relative large time series of a LAS-RWS system.

## FUTURE PLANS

In future research we will compare scintillometer derived fluxes of both $H$ and $L_vE$, collected during several measurement campaigns (see: www.met.wau.nl) over heterogeneous areas, with remote sensing methods based on NOAA-14 and LANDSAT satellite images. Especially for LANDSAT images one have to account for the spatial distribution of the pixels (resolution of ≈ 25m) in the source area of the scintillometer.

## ACKNOWLEDGEMENTS


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