2.2 RENAISSANCE OF SCINTILLOMETRY

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1. INTRODUCTION

In the 1970s impressive progress was made in research on turbulence and the use of scintillometers. Muschinski and Lenschow (2002) summarized the outcome of the workshop on “Future Directions for Research on Meter- and Submeter-Scale Atmospheric Turbulence” held at Boulder, Colorado, USA where the development in this field was discussed. One of their comments noted that, after a blooming period in the 1970s and consolidation in the 1980s, funding and interest in scintillometry faded rapidly in the early 1990s. This paper is a result of a renewed interest, a *renaissance,* in scintillometry. It presents some (not all) novel findings. Of work done in the last 40 years, some of the most important contributions include the work of Tatarskii (1961), the textbook by Monin and Yaglom (1975), the collection of scintillation papers brought together by Andreas (1990) and reviews by e.g. Hill (1997). Here are some main lines.

A scintillometer is an instrument that consists of a transmitter and a receiver. The receiver measures intensity fluctuations in the radiation emitted by the transmitter caused by refractive scattering of turbulent eddies in the scintillometer path. For laser sources, or small aperture scintillometers (SAS), the observed intensity fluctuations are a measure of the structure parameter of the refractive index, C_n^2, and the inner scale of turbulence, ℓ_0. For large aperture scintillometers (LAS), they are a measure of C_n^2 only. At optical wavelengths the contribution of temperature fluctuations dominates, i.e. the structure parameter of temperature C_T^2 can be deduced from the C_n^2 measurement. For radio wavelengths (> 1mm) on the other hand, water vapor fluctuations contribute most to the scintillometer signal, i.e. the structure parameter of moisture C_q^2 can be deduced from the C_n^2 measurement. Surface fluxes of sensible heat, latent heat and momentum can be determined from the obtained C_T^2, C_q^2 and ℓ_0 respectively by applying Monin-Obukhov similarity theory (MOST).

A number of length scales play a role in scintillometry:

- the inner and outer length scales of turbulence. The first, ℓ_0, is proportional to the Kolmogorov length $\left(\frac{\nu^3}{\varepsilon}\right)^{\frac{1}{4}}$, where ν is the molecular kinematic viscosity and ε the dissipation rate of turbulent kinetic energy (TKE). The outer length scale L_o is proportional to the height above the surface, z, in the surface layer.
- the wavelength of the light source of the scintillometer, λ.
- the aperture, *D*, of the scintillometer. Note that the transmitter and receiver have the same aperture in the scintillometers used in the studies presented here.
- the path length, *L*, of the scintillometer.
- the Fresnel zone, defined as $F \equiv \sqrt{\lambda L}$, is a measure of the size of the most active eddies in the scintillometer signal.

Recently, the Meteorology and Air Quality Group, of Wageningen University has been involved in several studies on scintillometry. Meijninger et al. (2002a), Beyrich et al. (2002), Hoedjes et al. (2002) and Kohsiek et al. (2002) used large aperture scintillometers (LAS). The LAS beam aperture diameter is referred to as “large” because it is larger than the Fresnel length. Meijninger et al. (b) used a LAS in

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combination with a (small aperture) radio wave scintillometer (RWS).

One aspect that has been investigated is the applicability of the scintillation method over heterogeneous surfaces. Since MOST applies to a horizontal, uniform terrain it was doubted whether scintillometry could be used over heterogeneous fields. Meijninger et al. (2002a) present experimental evidence that above the so-called *blending height* MOST is applicable over a heterogeneous terrain provided the LAS beam is still in the surface layer. They present results of the Flevoland experiment in the Netherlands, which was conducted over a flat heterogeneous terrain consisting of rectangular, agricultural fields with different crops. Beyrich et al. (2002) present results of the LITFASS experiment at Lindenberg, Germany, which took place over a very heterogeneous landscape consisting of a mixture of forest, grassland, arable land, villages and lakes. The LAS path length applied in these studies varied between 1 to 5 km and the LAS aperture was 0.15 m.
Kohsiek et al. (2002) were the first to use a LAS with an increased diameter of 0.3 m, which they called XLAS, and whose main advantage is that it can be applied over longer path lengths. They gathered data from an XLAS set-up over almost 10 km between the Cabauw tower and the TV tower at IJsselstein, in the Netherlands.

The applicability of scintillometers for hydrological purposes, where fluxes on the scale of watershed and water basins are needed, is investigated in Meijninger et al. (2002b). They applied two methods to determine the area-averaged flux of latent heat. First, they applied a two-wavelength method where both a LAS and a RWS were used. Secondly, they derived the latent heat flux from the sensible heat flux measured by the LAS and an estimate of the net radiation minus soil heat flux based on global radiation measurements.

Hoedjes et al. (2002) invesigated the application of the scintillation method under conditions of advection of dry air over irrigated areas. They found that existing MOST expressions still apply under daytime stable conditions where net radiation is positive. In that case the energy used for evaporation exceeds net radiation. This study shows that scintillometers can be used over irrigated areas.

All these scintillometer studies prove that it is possible to obtain reliable area-averaged fluxes at spatial scales up to 10 km. This allows experimental verification of fluxes determined with meteorological models and remote sensing techniques, which have a similar scale. Beyrich et al. (2002) compared LAS-derived fluxes with the operational model of the German Weather Service. In addition, they proved during a long-term study (one year) at Lindenberg that the LAS can routinely obtain sensible heat fluxes on an operational basis. Maintenance of the LAS and the data processing are comparable to that of other instruments at a standard meteorological station.

De Bruin et al. (2002) and Hartogensis et al. (2002) used a displaced-beam small aperture scintillometer (DBSAS). For this type *F* and *D* are of the same order as ℓ_0. With this instrument the light beam of one source is split into two parallel, displaced beams with orthogonal polarizations. The DBSAS yields directly an area average of ℓ_0, which is proportional to the dissipation rate of TKE, ε, and C_T^2. From both these the sensible heat flux and the momentum flux can be determined. This is an advantage over the LAS where, in order to solve for the sensible heat flux, an additional measurement is needed to infer the friction velocity, u_*. Other advantages of the DBSAS over traditional point measurements of surface fluxes are that it can yield fluxes very close to the surface and short averaging intervals can be used. De Bruin et al. (2002) compared the DBSAS-derived sensible heat flux and u_* with those from a hot-film eddy correlation system for stable and unstable conditions, for data gathered during the WINTEX experiment in Sweden. They discuss the theoretical background on which the DBSAS is based and identify possible sources of errors. A simple model is presented to account for the observed systematic deviations in u_*. Hartogensis et al. (2002) directly compared the DBSAS-derived l_o and C_T^2, as well as fluxes with those derived from eddy-covariance data for stable conditions, for data gathered during the CASES-99 experiment in Kansas, USA. They also discuss the applicability of DBSAS to determine fluxes over short time intervals. In addition, they discuss the sensitivity of the DBSAS determined l_o and C_T^2 to small offsets in the displacement distance between the two beams in relation to the assumed form of the refractive index spectrum in the dissipation range.

During the oral presentation of this paper several results of the studies described here briefly will be presented. It is not possible to include these in this extended abstract.

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