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A discussion on the paper "Large-aperture scintillometry – the homogeneous case" by MCaneney

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Outline

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▶1 Background

● The study draws heavily upon work done over the last 20 years at the NOAA Wave Propagation Laboratory in Boulder, CO.

● Recent advances in optical scintigraphy, published in astronomical journals, and recent advances in optical journals have been reported on various techniques for estimating the technical flux of surface heat and evaporation.

● Our approach here follows the procedure reported by Green et al.(1994): determinations of the structure constant for fluctuations in refractive index (C_N^2) were obtained directly from the LAS and then used with measurements of mean windspeed and rule-of-thumb assumptions about surface roughness to compute both H and u^*, via a simple iterative method.

►2 Physical principle

2.1 The refractive index structure parameter

In turbulence theory, it is common to describe the spatial variability by the so-called structure function $D_N(r)$. For separation distances r in the inertial sub-range of scales,

$$\boxed{D_N(r) = C_N^2 r^{2/3}} \qquad l_0 \le r \le L_0$$

For spatial scales $r >> L_0$, eddy motions are statistically independent and or twice the variance of the refractive index.

$$\boxed{D_N(r) \approx 2\sigma_N^2}$$

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2.2 The LAS： modus operandi

$$\boxed{\sigma_1^2 \propto C_n^2 l_0^{-7/3} L^3} \qquad (1)$$

where L is the distance between the transmitter and the receiver.
As the strength of the refractive turbulence increases, the scintillations saturate, i.e.,σ_1^2 does not continue to increase with increasing C_N^2 or L.

$$\boxed{\sigma_{\ln A}^2 = \overline{\left[\ln A - \overline{\ln A}\right]^2} = \int_0^1 C_n^2(u) W(u) du} \qquad (2)$$

where W(u) is a spatial-weighting function given by

$$\boxed{W(u) = 4\pi^2 k^2 L \int_0^\infty dKK\left(\phi_N(K)/C_n^2(u)\right)\sin^2\left(K^2 Lu(1-u)/2k\right) \times \left[2J_1(x_1)2J_1(x_2)/(x_1 x_2)\right]^2} \qquad (3)$$

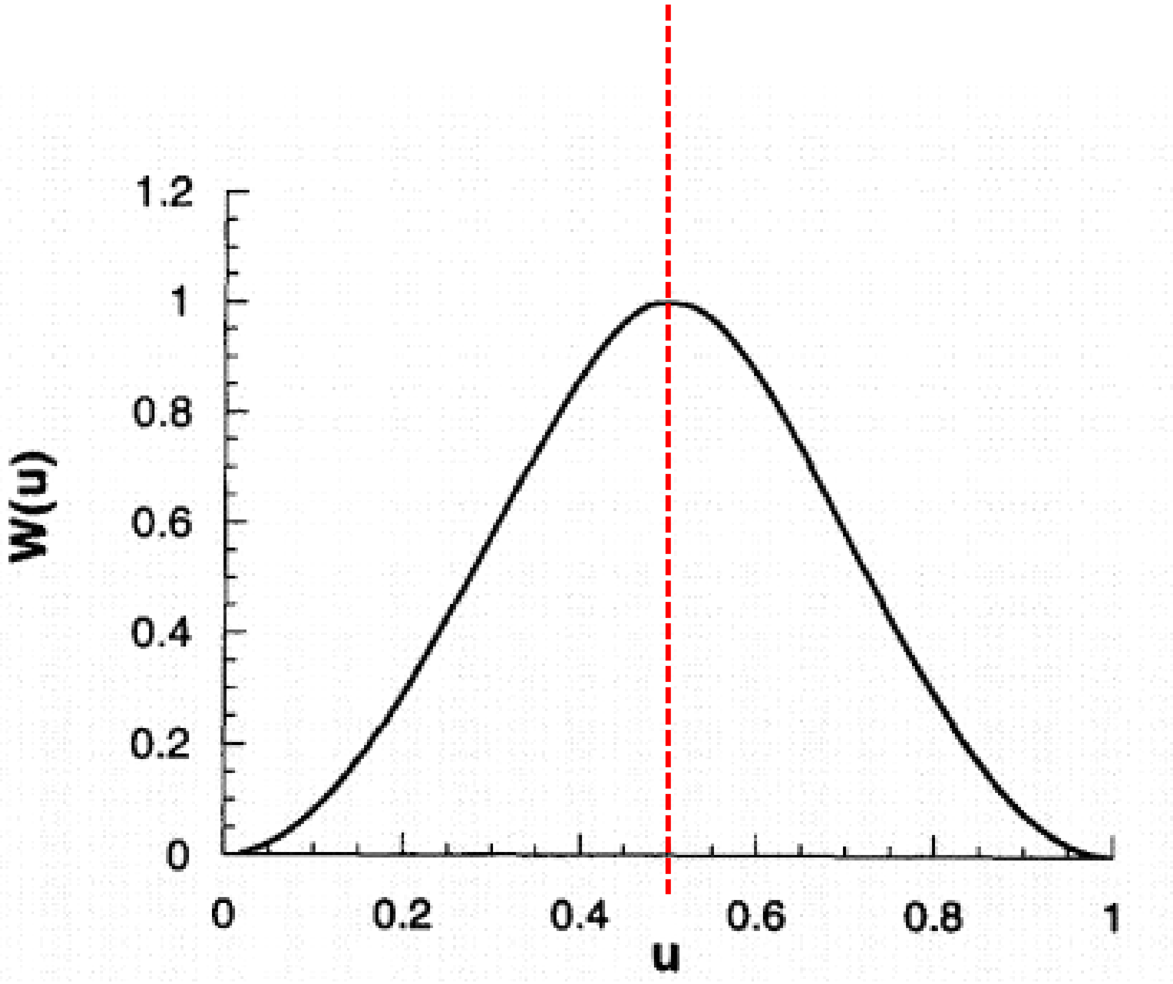

Fig. 1. Relative weighting function from Fq.(3) normalised to give unity at the mid pointposition.

It is bell-shaped symmetrical distribution, the optical path of the middle of the fluctuations in the measurement results of the greatest impact, and the receiver, transmitter near the fluctuations in interference is not sensitive.

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Whereas most micro meteorological sensors make point measurements, the LAS integrates turbulence over a finite volume. Thus, it is the 3-dimensional Kolmogorov spectrum of refractive index that is required:

$$\boxed{\phi_N(K) = 0.033 C_n^2 K^{-11/3}} \qquad (L_0^{-1} \le K \le l_0^{-1})$$

Substituting for $\phi_N(K)$ in Eqs. (2) and (3) and integrating numerically, Wang et al. (1978) obtained

$$\boxed{\sigma_{\ln I}^2 = 0.892 \overline{C_n^2} D^{-7/3} L^3} \qquad (4)$$

on the condition that transmitter and receiver apertures be equal and that

$$\boxed{D/(\lambda L)^{1/2} \quad (0.124 k^{7/6} L^{11/6} \overline{C_n^2})^{3/5}} \qquad (5)$$

2.3 Estimation of heat and momentum fluxes

$$C_T^2 = C_N^2 (T^2/\gamma P)^2 (1 + 0.03/\beta)^2 \qquad (6)$$

$$T* = H/\rho C_p u* \qquad (7)$$

$$C_T^2 / T_*^2 z^{-2/3} = f(\xi) = 4.9(1 + 7|\xi|)^{-2/3} \qquad (8)$$

$$\xi = z/L_{mo} = -(z - d_0) g k T*(1 + 0.07/\beta)/u*^2 T \qquad (9)$$

$$u* = kU / \ln\left[((z - d)/z_0 - \psi_m(\xi)\right] \qquad (10)$$

$$\psi_m = \ln\left[((1 + x^2)/2((1 + x)/2)^2\right] - 2\arctan x + \pi/2$$

where

$$x = (1 - 16z/L_{mo})^{1/4}$$

For homogeneous vegetative surfaces, z_0 and d_0 can be taken as fractions of the vegetation height (h_c)

$$d_o \approx 0.65\, h_c \; and \; z_o \approx 0.13\, h_c$$

$$\lambda_v E = (R_n - G) - H$$

▶3 Experimental

Field tests of the LAS were undertaken in mid-summer to early autumn 1994 over a flat, exposed pastural site on the Purerua Peninsula (lat. 35° 16'S; long. 173° 55'E). The large-aperture scintillometer was mounted at a height of 1.4 m above the ground on a plinth constructed of concrete blocks. Path length was 350 m.Away to one side of the midway position and at the same height of the optical path, a simple stayed mast supported eddy correlation instruments.Data was processed on-line to output 30-minute averages of covariances between the variables of interest and the statistics required for the calculation of energy budget components and other derived variables.Sampling frequency was 10 and 1 Hz for eddy correlation and for the scintillometer, respectively;

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▶4 Results and discussion

4.1 Experimental

$$u_{sc}{}^{*} = 0.99(\pm 0.011)\, u_{ed}{}^{*}$$

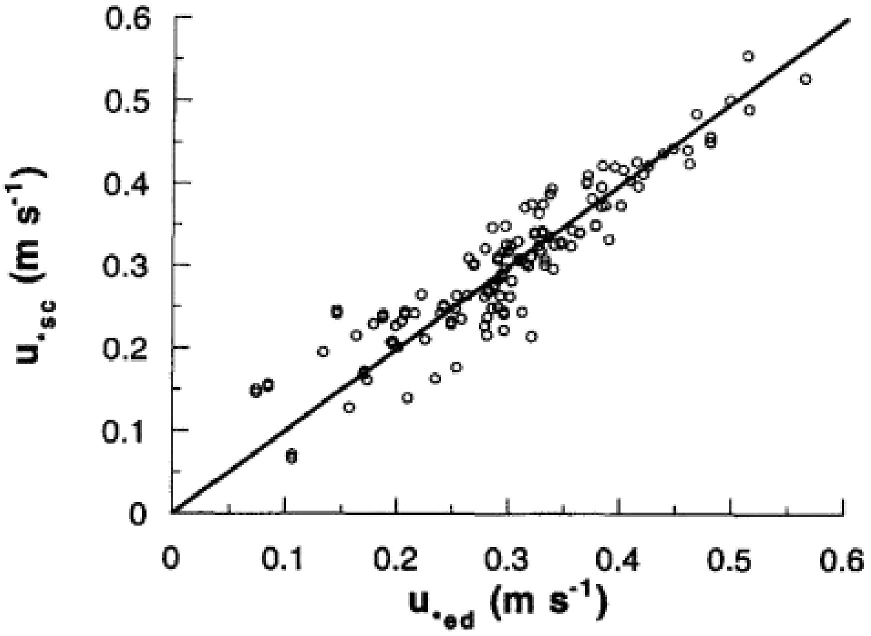

Fig 3.Comparison of friction velocities from the mean windspeed and eddy correlation instruments.Line indicates the 1:1 relationship

$$H_{sc} = 1.07(\pm 0.014)\, H_{ed}$$

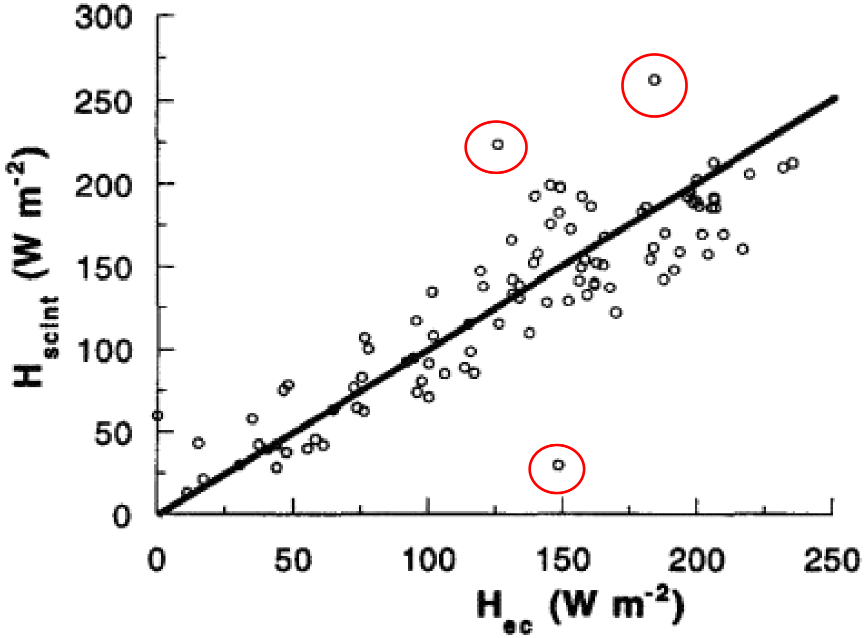

Fig 4.Comparison of sensible heat fluxes as measured by scintillation and mean windspeed and by eddy correlation, Data represented by solid symbols were excluded from the regression analysis. Line indicates the 1:1 relationship.

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4.2 Advantages of optical scintillometry

① If we examine the relation (5) （ $D/(\lambda L)^{1/2} \quad (0.124 k^{7/6} L^{11/6} \overline{C_n{}^2})^{3/5}$ ） in terms of a maximum path-length (Lmax) for a given D,we find:

$$L_{\max} \quad D^{5/8} \lambda^{1/8} \left(\overline{C_n{}^2}\right)_{\max}^{-3/8}$$

Substituting for D and a high value of C_n^2 suggests a maximum path length of around 1.7 km. This is a significant advance over the diode-laser system described by Green et al. (1994), which has a maximum range of some 150 to 200 m. This increased range is more compatible with current interests in boundary layer studies and comparable with the spatial resolution of thermal infrared channels of the NOAA satellites.

4.2 Advantages of optical scintillometry

②A further advantage over conventional techniques is decreased averaging times to reduce statistical uncertainty in turbulence measurements.

③The bell-shaped path-weighted function, which is not sensitive to fluctuations in the vicinity of the receiver and emitter, and thus avoids the effects of obstructions.The damage or opacity of the window will also have no effect on the measured C_n^2.

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▶5 Summary

Sensible heat fluxes and friction velocities, as determined from a large-aperture scintillometer and measurements of mean windspeed, provided close agreement with values obtained with eddy correlation. The LAS appears reliable and offers an order of magnitude improvement in averaging times required to achieve a given accuracy in flux measurements over eddy correlation.This study has clearly shown the average LAS capacity of the line under uniform surface, but the effect of the technique on uneven surface conditions remains to be tested.

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Thank you