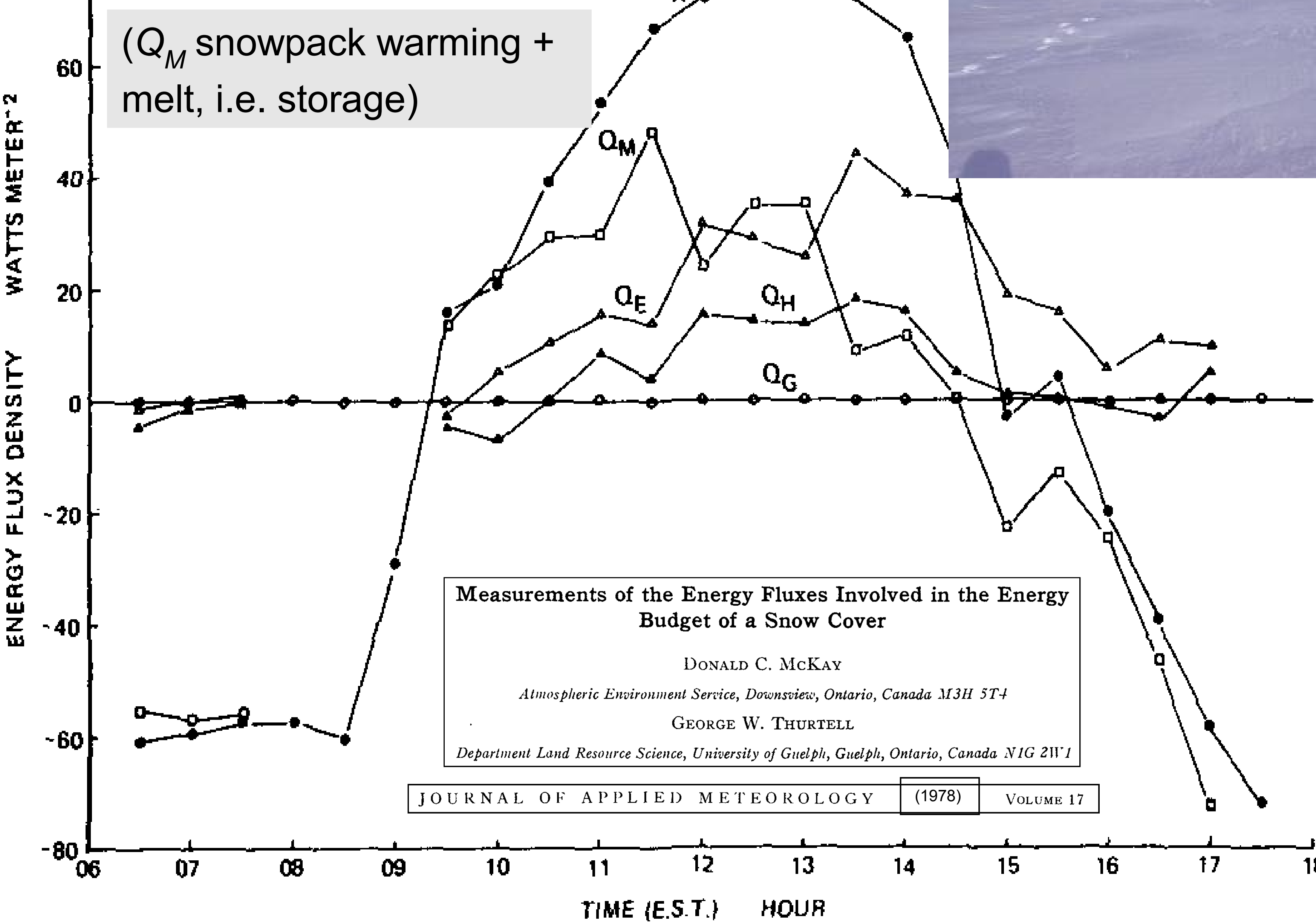
27 Sep., 2012

Slides relating to the atmospheric surface layer

Winter Energy Balance Elora, Ontario

$$Q_N = Q_H + Q_E + Q_M + Q_G$$

(Q_M snowpack warming + melt, i.e. storage)



Measurements of the Energy Fluxes Involved in the Energy Budget of a Snow Cover

DONALD C. MCKAY

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GEORGE W. THURTELL

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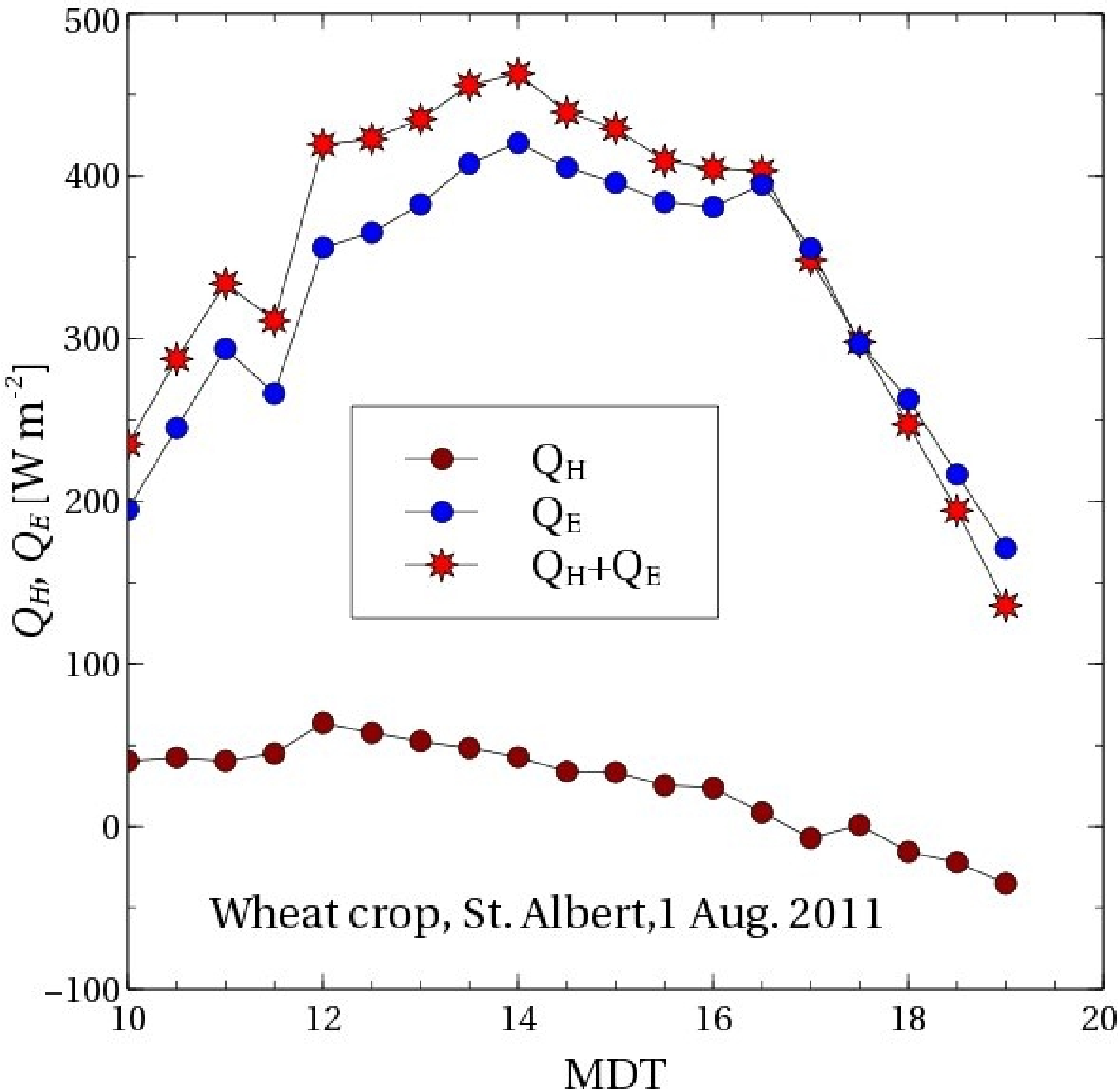
JOURNAL OF APPLIED METEOROLOGY (1978) VOLUME 17

Sensible and latent heat flux densities (1 Aug. 2011, St. Albert)



INTRODUCTION TO OBUKHOV'S PAPER ON 'TURBULENCE IN AN ATMOSPHERE WITH A NON-UNIFORM TEMPERATURE'*

J. A. BUSINGER

Department of Atmospheric Sciences, University of Washington, Seattle, Wash., U.S.A.

and

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(Received 1 April, 1971)

In 1943 at the age of 25, A. M. Obukhov finished the remarkable paper that follows this brief introduction. Because World War II ravaged around the globe at that time this manuscript was not published until 1946. Unfortunately, however, it appeared in the very limited first issue of the Journal: *Trudy Instituta Teoreticheskio Geofiziki AN SSSR* (Works of the Institute of Theoretical Geophysics, Acad. Sci. USSR, No. 1). So without the aid of modern duplicating techniques, the paper was doomed to obscurity right from the start. Very few scientists outside the Soviet Union were aware of it and even in the U.S.S.R. not many realized its real importance.

At present, nearly 25 yr after its publication, most of the information it contains is known to the scientific community, partly from the original source and partly by independent rediscovery. Nevertheless, it seems fully justified to give this paper new exposure because it is a truly classical contribution and every serious student of the atmospheric boundary layer should have the opportunity to study it.

Probably the major contribution of the paper is the introduction of the 'length scale of the dynamic turbulence sublayer', L_1. This length scale was later introduced independently by Lettau (1949), and at present it is commonly known as the Monin-Obukhov length. Its fundamental role in the whole field of boundary-layer meteorology was most clearly explained in the well-known paper by Monin and Obukhov (1954). In this last paper the presentation is based on purely dimensional considerations which imply that the mean wind and temperature profiles must be determined by some universal function of the uniquely defined (to within a numerical factor) dimensionless height $\zeta = z/L_1$. (Let us note that Obukhov included the numerical factor $1/k$, where k is the von Karman constant, in the definition of L_1 which does not follow from dimensional considerations. The same factor was also included in the definition of length scale by Monin and Obukhov in 1954 and is used in practically all subsequent works although its presence produces some difficulties in comparison of the data

* Contribution No. 241, University of Washington, Dept. of Atmospheric Science.

Monin-Obukhov similarity theory

- applies in hh_ASL, at heights
    - not too close to ground
    - not too far from ground
- empirical
- basis for scaling observed statistics; provides better ordering than any earlier suggestion(s), including those based on the Richardson number
- imperfect, yet hard to beat for parsimony
- "extended MOST" adds ABL depth as a scaling parameter

The Obukhov length

$$L = \frac{-\,u_*^3}{k_v\,\frac{g}{T_R}\,\overline{w'T'}} \qquad \xrightarrow[0]{\overline{w'T'}} \qquad \pm\infty$$

← decreasingly unstable ← → decreasingly stable → neutral

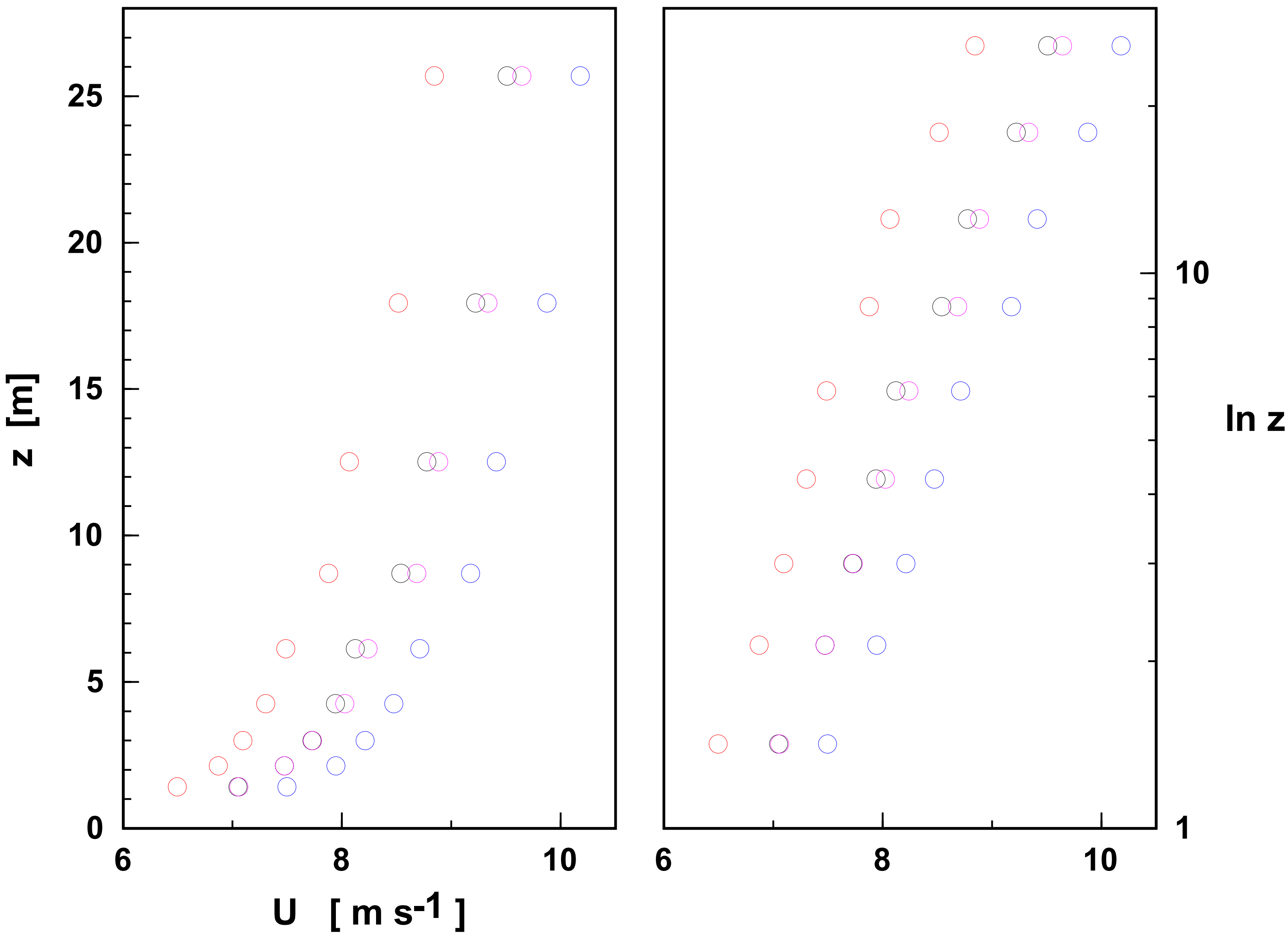
0 → L

increasingly unstable ← neutral → increasingly stable

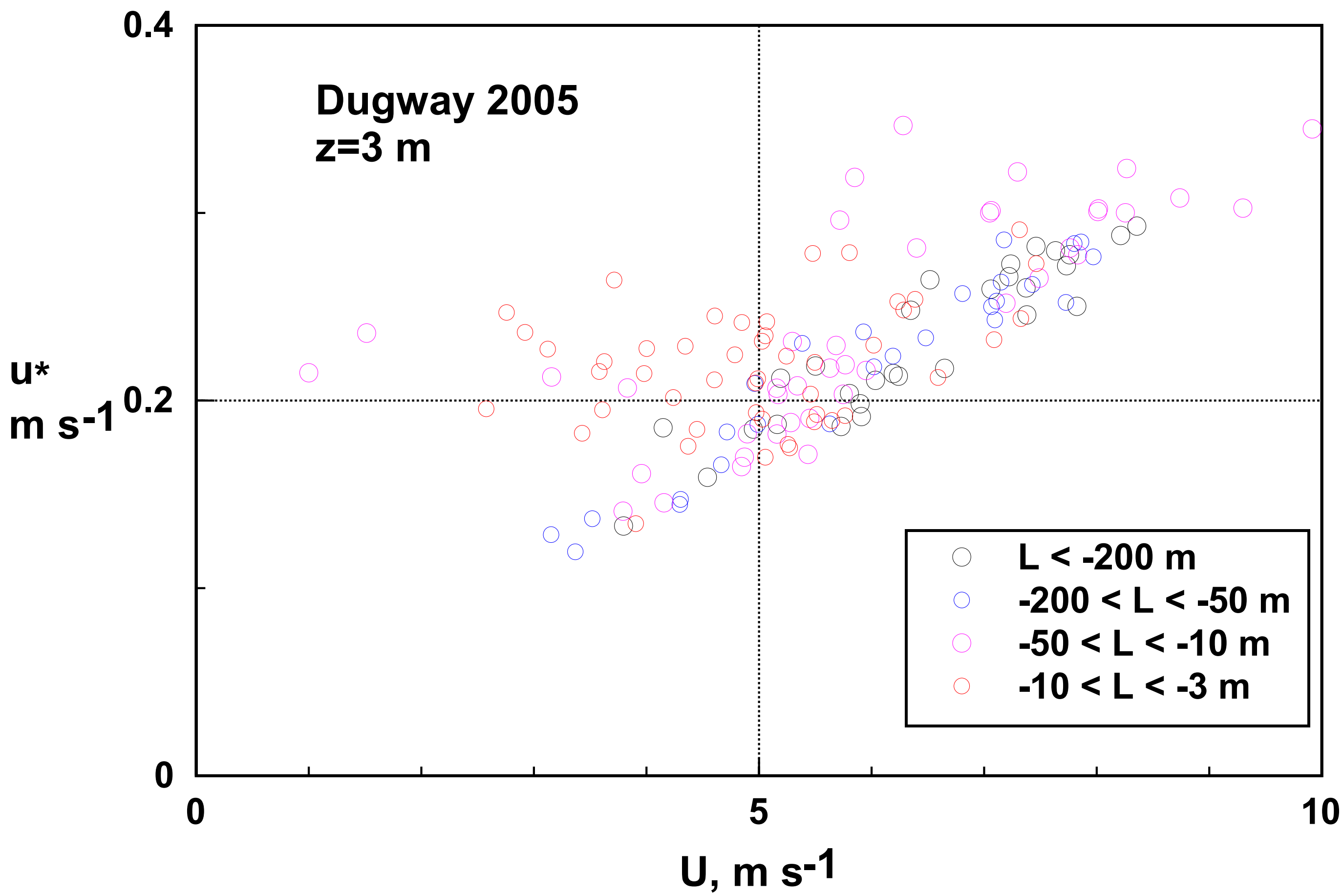
0 → $1/L$

Dugway Proving Grounds, Utah, 2005 – 18 sonics, 50 km fetch

Neutral wind profile – three near-neutral, 30 min runs, Dugway



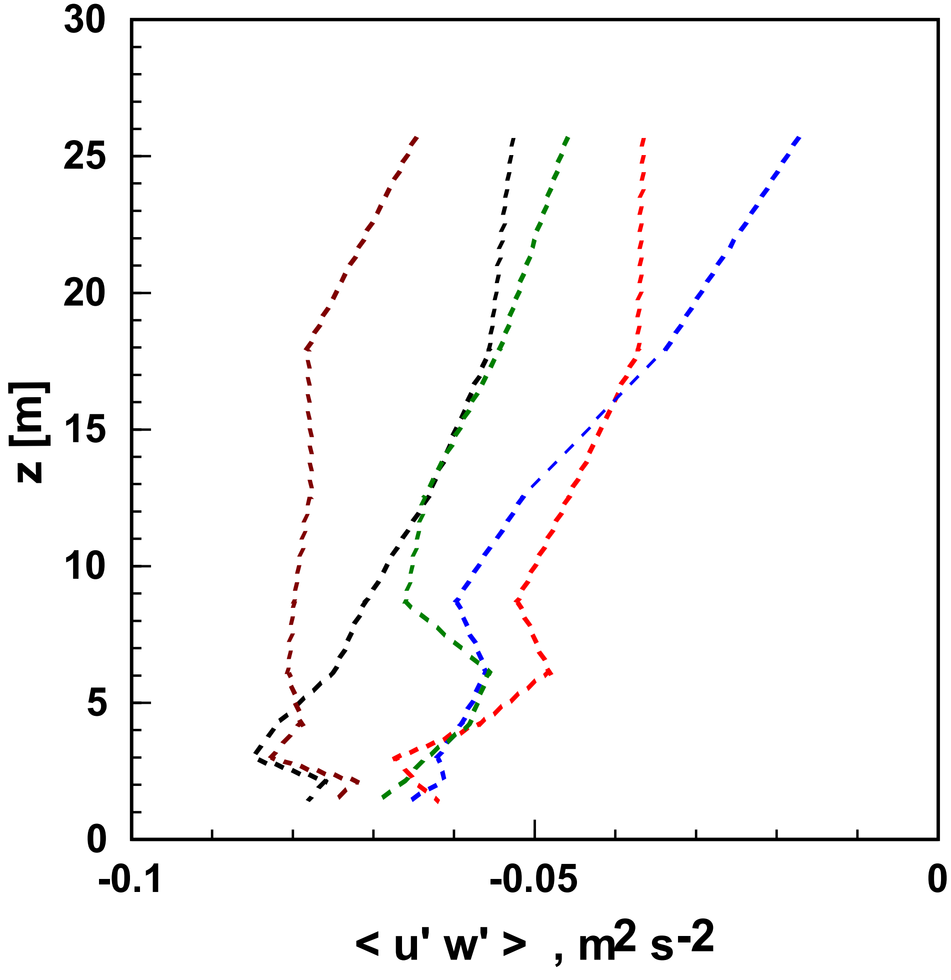
Typical values of the friction velocity (assuming a wind strong enough to feel, but not a gale) span about 0.1- 0.5 m s^{-1}

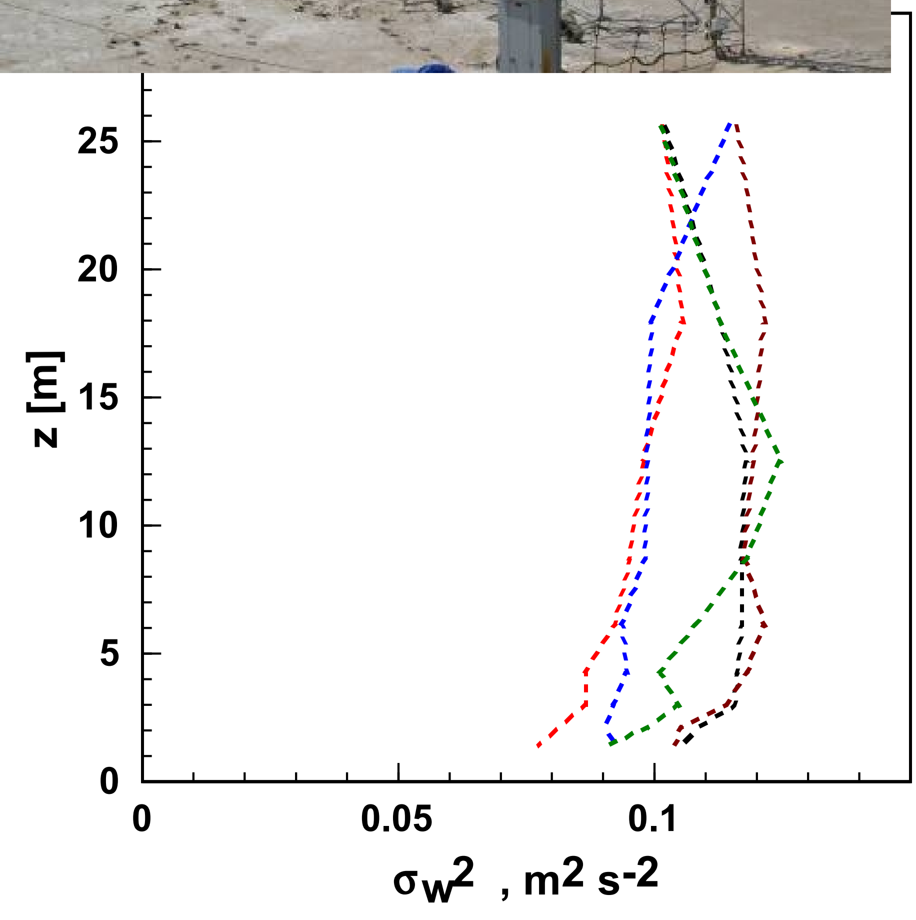


$$L = \frac{-u_{*0}^{3}}{k_v \frac{g}{T_0} \overline{w'T'}_0}$$

Dugway: four 30 min runs, all with $|L| > 200$ m (near neutral)

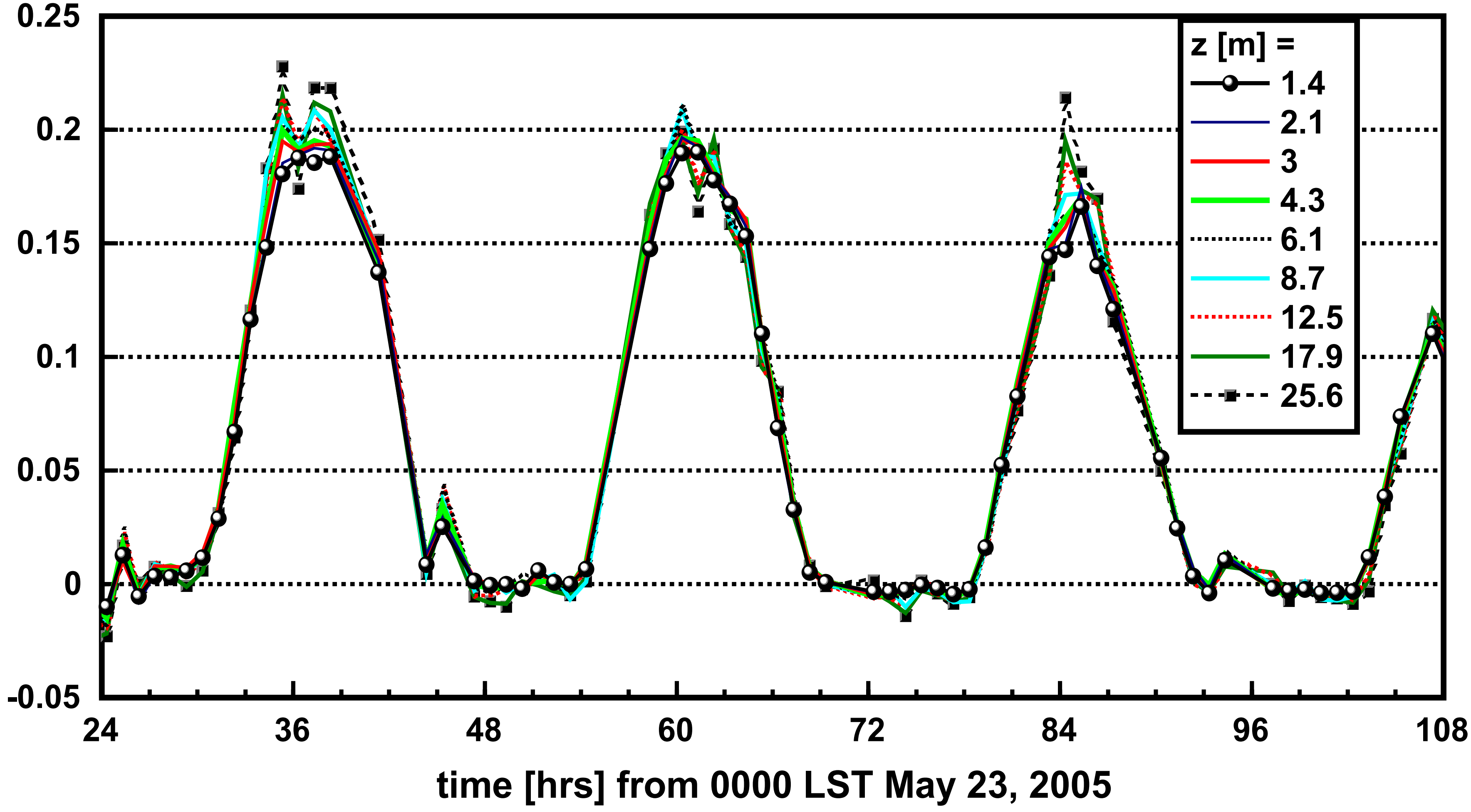
Note the height-variation of the shear stress: constant stress layer?



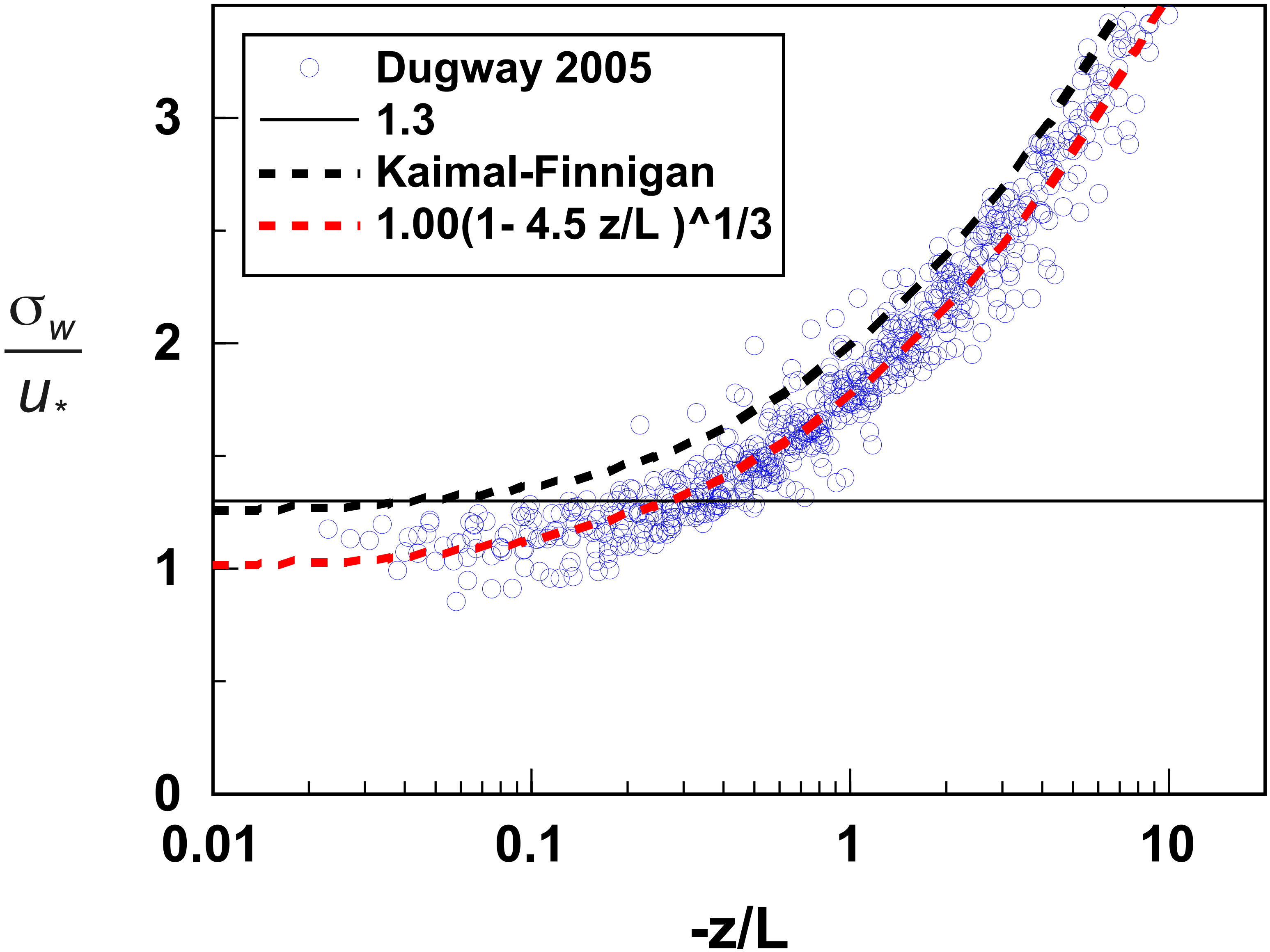


Fractional height-variation of the heat flux is *small*

$\overline{w'T'}\ \mathrm{ms^{-1}K}$



Fractional height-variation of the heat flux is *small*



$$\frac{\sigma_w}{u_*} = 1.0 \left(1 - 4.5 \frac{z}{L}\right)^{1/3}$$

Boundary-Layer Meteorol (2008) 129:353–369
DOI 10.1007/s10546-008-9319-5

ORIGINAL PAPER

Monin-Obukhov Functions for Standard Deviations of Velocity

J. D. Wilson

Please read Sections 1,2 of this paper

Received: 16 March 2008 / Accepted: 11 September 2008 / Published online: 8 October 2008

Abstract The origins of Monin-Obukhov similarity theory (MOST) are briefly reviewed, as a context for the analysis of signals from sonic anemometers operating in the surface layer over a Utah salt flat. At this site (over the interval of these measurements) the neutral limit for the normalized vertical velocity standard deviation (σ_w/u_*) deviates markedly from what has generally been regarded as the standard value (i.e. about 1.3), suggesting (since others have also reported such deviations) that this Monin-Obukhov constant is not, in fact, universal. New (but tentative) formulae are suggested for σ_w and for the longitudinal standard deviation σ_u.

Boundary-Layer Meteorol (2009) 132:193–204
DOI 10.1007/s10546-009-9399-x

ARTICLE

Turbulent Kinetic Energy Dissipation in the Surface Layer

D. Charuchittipan · J. D. Wilson

Please read Section 1 of this paper

Received: 20 January 2009 / Accepted: 2 June 2009 / Published online: 19 June 2009

Abstract We estimated the turbulent kinetic energy (TKE) dissipation rate (ϵ) for thirty-two 1-h intervals of unstable stratification covering the stability range $0.12 \leq -z/L \leq 43$ (z/L is the ratio of instrument height to the Obukhov length), by fitting Kolmogorov's inertial subrange spectrum to streamwise spectra observed over a desert flat. Estimated values are compatible with the existence of local equilibrium, in that the TKE dissipation rate approximately equalled the sum of shear and buoyant production rates. Only in the neutral limit was the turbulent transport term in the TKE budget measured to be small.

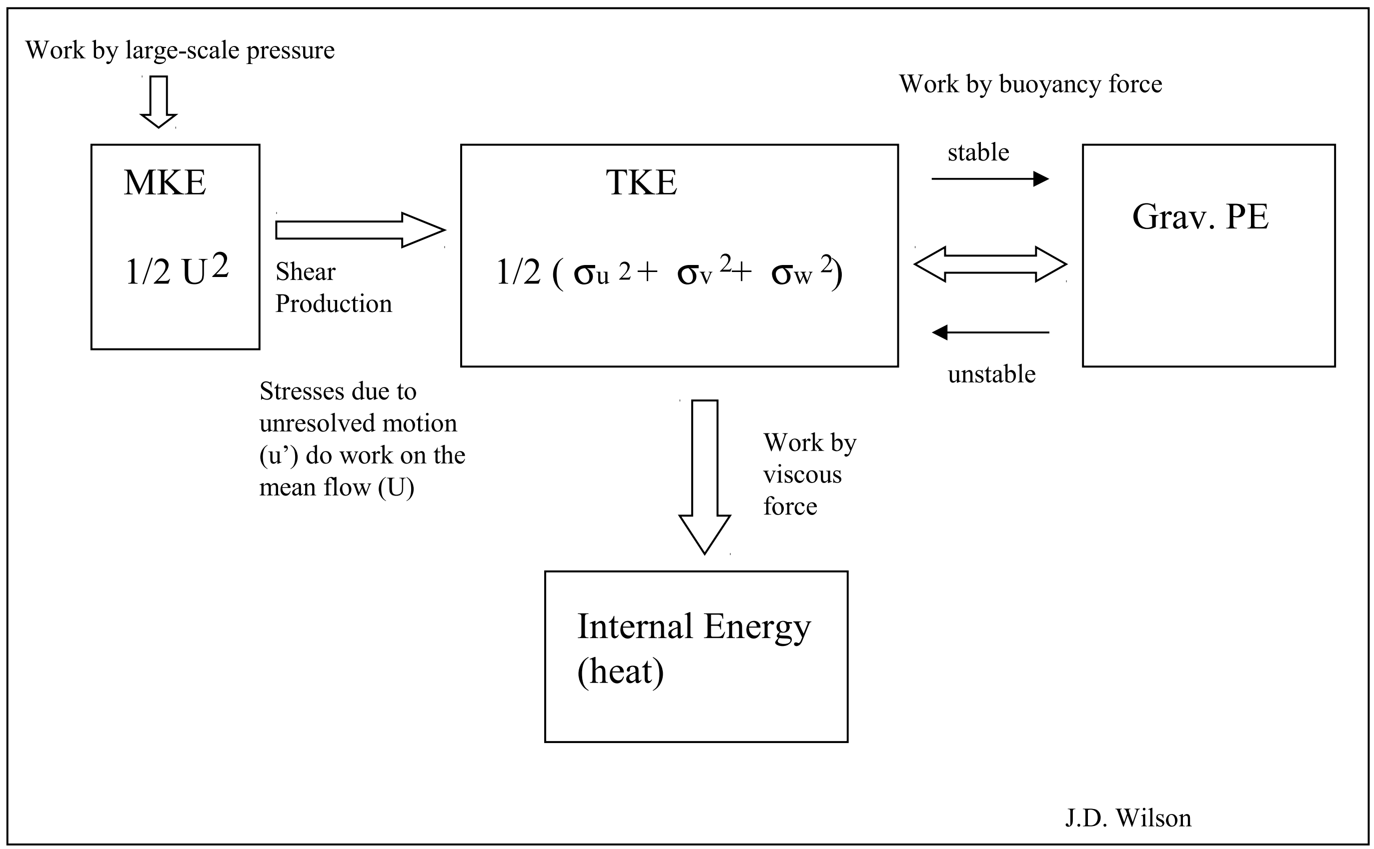
Flux Richardson number $R_i{}^f = \dfrac{\frac{g}{T_0}\,\overline{w'T'}}{\overline{u'w'}\,\frac{\partial \overline{u}}{\partial z}}$ (negative in unstable stratification)

er relate this to the "gradient Richardson number" $R_i^g = \dfrac{\frac{g}{T_0}\,\frac{\partial \overline{\theta}}{\partial z}}{\left(\frac{\partial \overline{u}}{\partial z}\right)^2}$

Lewis Fry Richardson (1881-1953)

- ambulance driver, WW1 France
- in off-duty time, embarked on test of his mathematical weather forecasting method. Had taken with him to France observations for 7 a.m., 20 May 1910
- by 1916, wrote *Weather Prediction by Arithmetic Finite Differences…*

Bulk TKE budget



Quart. J. R. Met. Soc. (1971), **97**, pp. 168-180

551.507.7 : 551.508 : 551.510.522 : 551.551.8

An experimental study of Reynolds stress and heat flux in the atmospheric surface layer

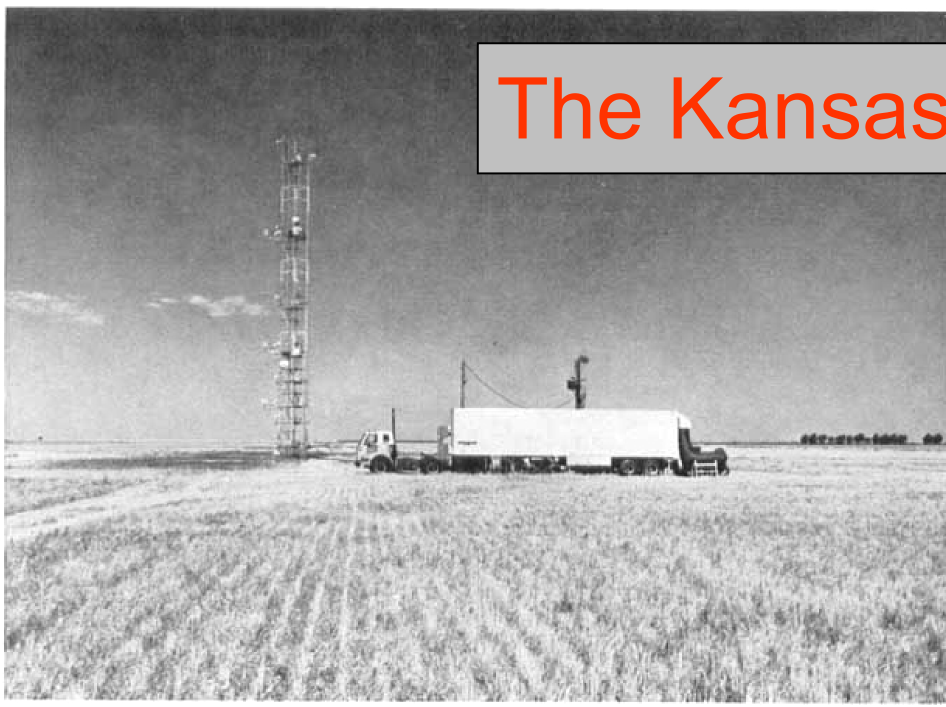
By D. A. HAUGEN, J. C. KAIMAL and E. F. BRADLEY

Air Force Cambridge Research Laboratories *CSIRO, Canberra, Australia*

The paper describes an experimental programme to study the characteristics of momentum and heat transport in the first 22·6 m of the atmosphere. Sonic anemometers and fine platinum wire thermometers were used for flux computations by the eddy correlation technique. Two drag plates were used to measure the surface stress.

The results indicate that the fluxes are constant with height to within ±20 per cent provided a long enough averaging period is chosen. Shorter averaging periods (15 min or less) show considerable variation in the fluxes and in their vertical gradients especially during unstable conditions. It appears that much of this variability can be attributed to the strong effect on the fluxes of submesoscale circulations. The momentum flux gradient seems to be particularly sensitive to these circulations.

The Kansas Experiment



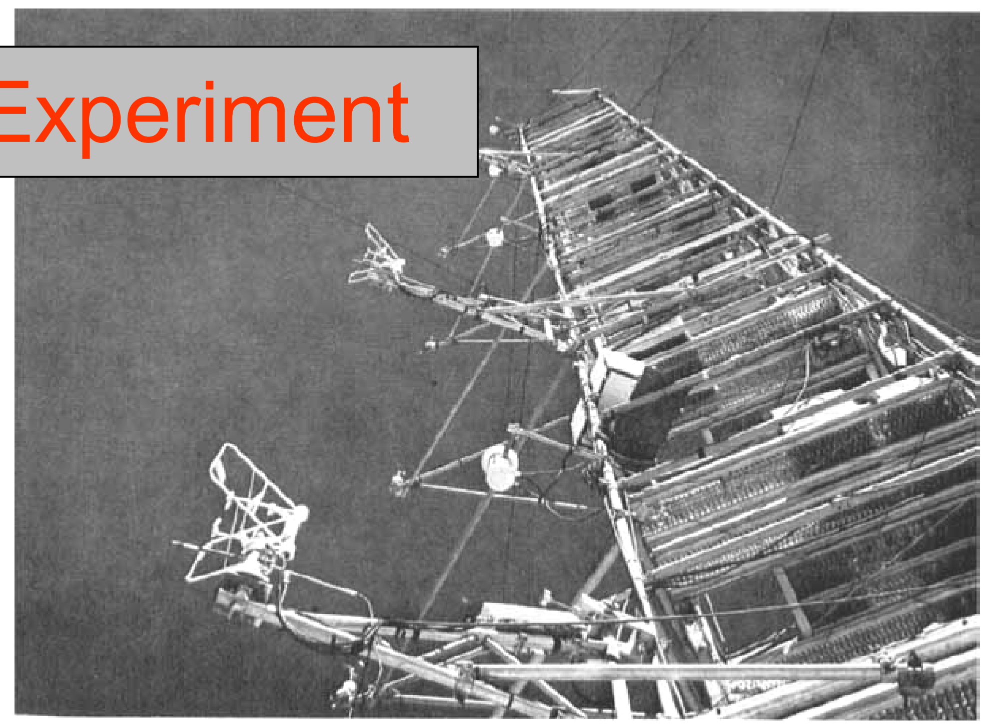


Figure 1. View of experiment site in Kansas showing instrumented van and tower.

The Kansas Experiment **

Flux-Profile Relationships in the Atmospheric Surface Layer

J. A. Businger,[1] J. C. Wyngaard,[2] Y. Izumi[2] and E. F. Bradley[3]

(Manuscript received 27 July 1970)

ABSTRACT **(J. Atmos. Sci., Vol. 28, 1971)**

Wind and temperature profiles for a wide range of stability conditions have been analyzed in the context of Monin-Obukhov similarity theory. Direct measurements of heat and momentum fluxes enabled determination of the Obukhov length L, a key independent variable in the steady-state, horizontally homogeneous, atmospheric surface layer. The free constants in several interpolation formulas can be adjusted to give excellent fits to the wind and temperature gradient data. The behavior of the gradients under neutral con-

$$\mathrm{Ri}=\frac{g\partial\bar{\theta}/\partial z}{\bar{\theta}(\partial\bar{U}/\partial z)^2}$$ Richardson number, a stability parameter (1)

$$\phi_m=\frac{kz}{u_*}\frac{\partial\bar{U}}{\partial z}$$ A dimensionless wind shear (2)

$$\phi_h=\frac{z}{\theta_*}\frac{\partial\bar{\theta}}{\partial z}$$ A dimensionless temperature gradient (3)

$$\alpha=\frac{K_h}{K_m}=\frac{\overline{w'\theta'}}{\overline{u'w'}}\frac{\partial\bar{U}/\partial z}{\partial\bar{\theta}/\partial z}$$ Ratio of the eddy transfer coefficients (4)

$$\zeta=\frac{z}{L}=-\frac{kg\overline{w'\theta'}z}{\bar{\theta}u_*^3}$$ A dimensionless height (5)

MOST was found to organize the observations beautifully. However there was later a controversy regarding possible flow distortion by boxes on the tower. The Kansas expts. gave what is now regarded as an anomalously small von Karman const.

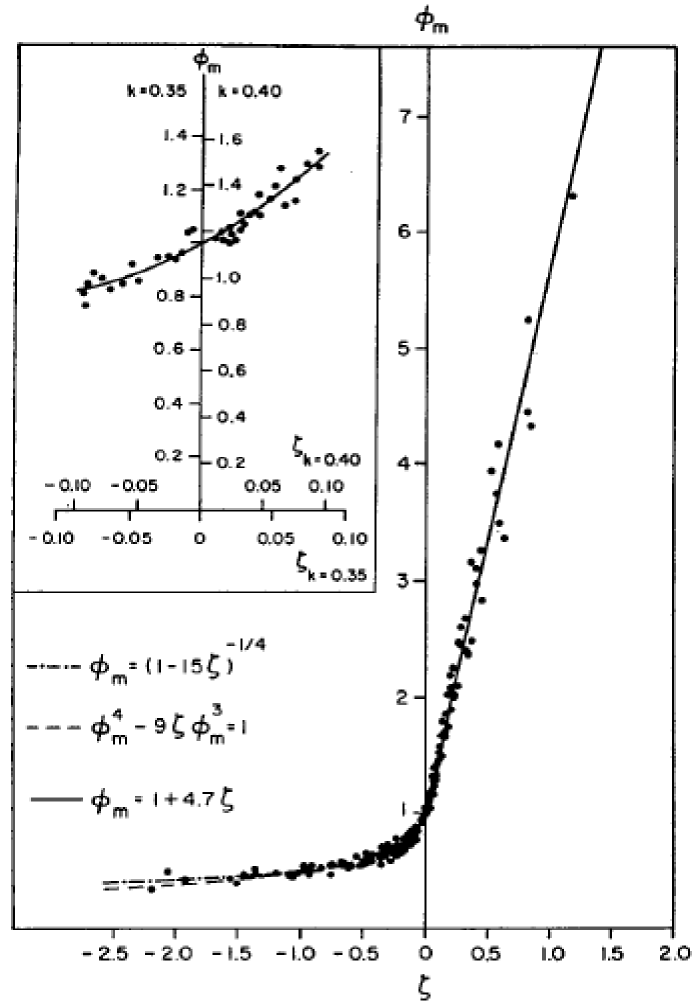


Fig. 1. Comparison of dimensionless wind shear observations with interpolation formulas.

** See also Kaimal et al. (1972; QJRMS Vol. 98): "Spectral characteristics of surface-layer turbulence"

AN INTERNATIONAL TURBULENCE COMPARISON EXPERIMENT (ITCE 1976)

A. J. DYER, J. R. GARRATT, R. J. FRANCEY, I. C. McILROY, N. E. BACON, P. HYSON

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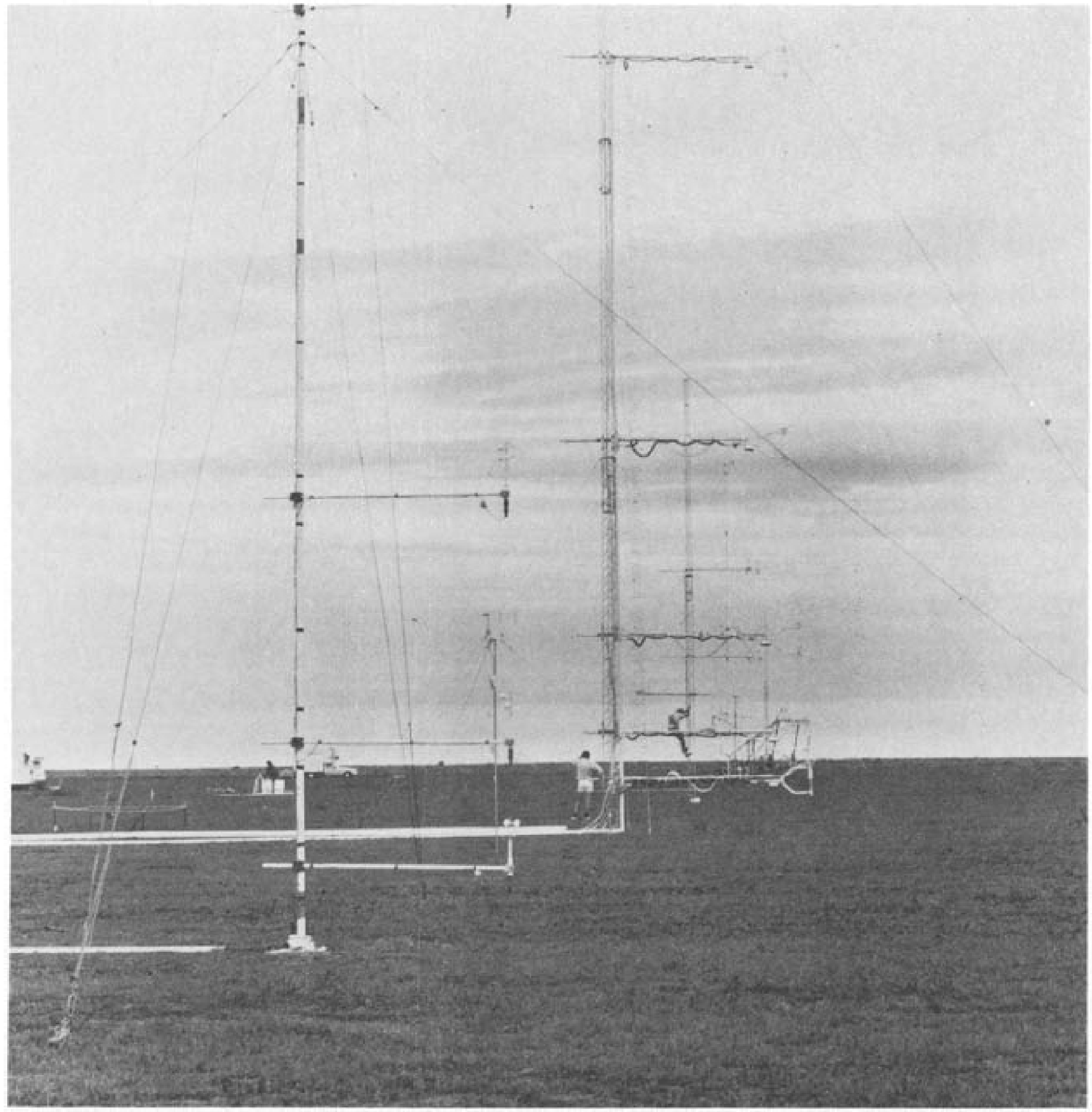
(Received 14 July, 1982)



AN ALTERNATIVE ANALYSIS OF FLUX-GRADIENT RELATIONSHIPS AT THE 1976 ITCE

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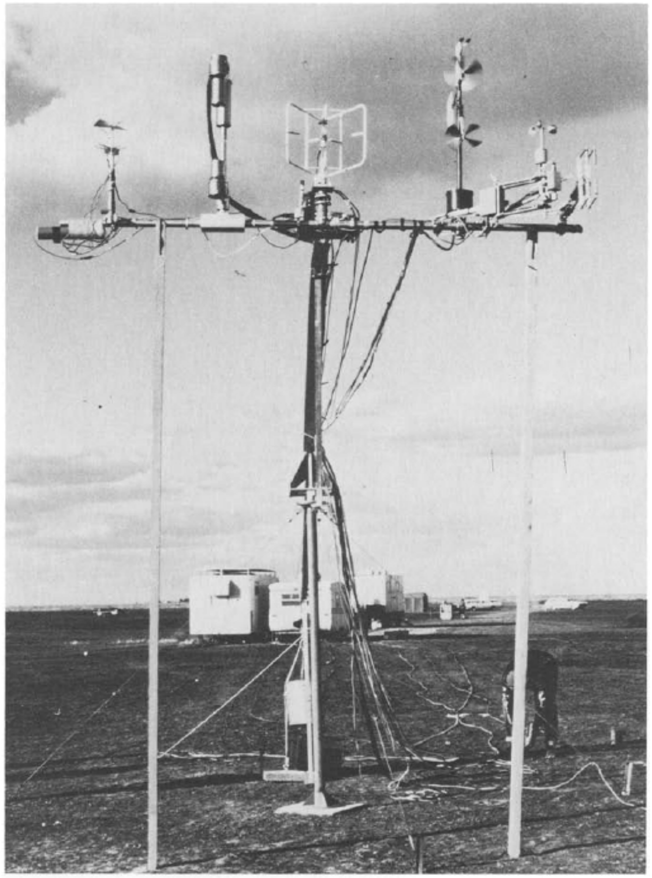
and

E. F. BRADLEY
CSIRO Division of Environmental Mechanics, Canberra, A.C.T., Australia

(1982; Bound. Layer Meteorol., Vol. 22)



Assumed:

$$\frac{k_{vm} z}{u_*} \frac{\partial \overline{u}}{\partial z} = \phi_m\left(\frac{z}{L}\right)$$

$$\frac{k_{vh} z}{T_*} \frac{\partial \overline{\theta}}{\partial z} = \phi_h\left(\frac{z}{L}\right)$$

$$\frac{k_{vw} z}{\rho_{v*}} \frac{\partial \overline{\rho}_v}{\partial z} = \phi_w\left(\frac{z}{L}\right)$$

and that all phi's tend to unity in neutral limit (allowing possib. of distinct von K consts).

Concluded:

$$k_{vm} = k_{vh} = k_{vw} = 0.4$$

$$\left.\begin{aligned} \phi_m &= \left(1 - 28\,\frac{z}{L}\right)^{-\frac{1}{4}} \\ \phi_h = \phi_w &= \left(1 - 14\frac{z}{L}\right)^{-\frac{1}{2}} \end{aligned}\right\} \quad -4 \le z/L \le -0.004$$

"The evidence is mounting that the atmosphere does not follow the averaged laws at all places and all times even over an excellent site"