JOINT COLLOQUIA

29 June 1967

THE MEASUREMENT OF EDDY FLUXES IN THE LOWER ATMOSPHERE

By A.J. Dyer

Dr. Dyer of the Division of Meteorological Physics, C.S.I.R.O., Aspendale, in opening his talk referred to the pioneering work carried out over a number of years by several members of the Division which has resulted in the successful measurement of eddy fluxes of heat, water vapour and momentum. These fluxes are important in assessing energy and momentum interactions between the global surface and the atmosphere. This work has an application to numerical forecasting as well as to general transfer problems near the surface. The basic equations used are

$$H = -\rho\ C_p\ K_H \frac{\partial\theta}{\partial z} \qquad \ldots (1)$$

$$E = -\rho\ l\ K_W \frac{\partial q}{\partial z} \qquad \ldots (2)$$

$$\gamma = \rho\ K_M \frac{\partial u}{\partial z} \qquad \ldots (3)$$

where θ, q and u refer to temperature, water vapour and wind speed. The usual constants ρ, C_p and l designate density, specific heat at constant pressure and latent heat of vaporization. K_H, K_W and K_M refer to exchange coefficients for heat, water vapour and momentum respectively. These coefficients can vary from values of the order of 10^{-2} cm^2 sec^{-1} for calm conditions to 10^9 cm^2 sec^{-1} at stratospheric levels and the justification for equating K_H and K_M has been the subject of much controversy. The eddy correlation method has been used to investigate these relationships. The "Evapotron" was developed in conjunction with this technique. An essential requirement in the instrumentation was that the sensing and recording elements should be sufficiently fast in response to detect vertical eddy fluxes such as that of sensible heat. The vertical eddy flux of sensible heat (H) can be related to instantaneous values of the vertical wind component (W') and air-temperature (T') by

$$H = \rho\ C_p\ (\overline{W}\ \overline{T} + \overline{W'T'}) \qquad \ldots (4)$$

$$\text{also}\quad W'\ T' = \overline{W'_e\ T'_e} - \overline{W'_e}\ \overline{T'_e} \qquad \ldots (5)$$

Here the prime denotes a departure from the mean and the bar a time average. Since precise mean values for vertical wind component (W) and air temperature (T) cannot be known in advance, it is not possible for any instrument to assess immediately W' and T'. This difficulty is overcome by detected departures from working means W_e and T_e. Equation (4) is made up of a mean and an eddy flux term. As a turbulent or mean flow could result from short or long term exposure, time limits were imposed on readings. The threshold value for the instrument decided the lower value and neglecting the mean flow term $\overline{W}\ \overline{T}$ imposed an upper limit. Errors appear due to random errors in machinery and also due to horizontal transport of heat. The results using the Evapotron gave good results for H and fairly good for E, but results for momentum were not as good as had been desired. Stress was placed on the importance of selecting a suitable site to carry out these experiments.

More recently the 'Fluxatron' has been developed which incorporates propeller sensors to determine u and W. The eddy flux distribution against time assumes a Gaussian form. Near one second the spectrum is large and well defined; at the other extremity near 60 seconds the distribution fluctuates from plus to minus. As the latter does not contribute to eddy flux it was filtered out. This left $W'\ T' = \overline{W'_e\ T'_e}$ in Equation 5. A logarithmic wind profile has been used.

$$\frac{\partial u}{\partial z} = u_*/kz$$

where u_* is an auxiliary reference velocity called the friction velocity and k is von Karman's constant.

The Monin Obukhov universal functions ϕ_H, ϕ_M, ϕ_W were then introduced in an attempt to determine their variation with the stability parameter z/L where L is the Monin Obukhov constant. A suitable framework for analysis of the flux profile relationship is then provided in the Monin Obukhov form

$$\frac{\partial \theta}{\partial z} = -H(\rho C_p k\ u_* z)^{-1} \quad \phi_H\ (\frac{z}{L}).$$

In order to evaluate ϕ_H, ϕ_M, ϕ_W, the potential temperature gradient $\frac{\partial \theta}{\partial z}$ was assumed to be equal to $\Delta\theta/\Delta z$ for adjacent heights and taken as applicable at the geometric mean height for z between 1 and 2 metres. In order to evaluate u_*, near neutral conditions were assumed near the surface where ϕ was taken as equal to unity. A series of slides was shown with plots of the universal functions ϕ_H, ϕ_W and ϕ_M against -z/L. In the case of ϕ_H and ϕ_M points representing results from different heights for overlapping regions of z/L meshed nicely and approximated a curve approaching unity for small values of z/L. Such curves can be looked upon as empirical solutions to the problem and it was possible to equate the transfer coefficients for heat and water vapour, writing

$$\phi_H,\ \phi_W = (1 - 15\ \frac{z}{L})^{-0.55}$$

Thus the transfer coefficients K_H and K_W have been successfully evaluated. Whilst the attempt to value K_M is not completely successful at present, the desired solution seems to be in sight.

During question time the opportunity was taken to seek further advice from Dr. Dyer on certain aspects of his work. The major discussion that ensued can be summarised by the following selection of questions. Mr. Hounam queried the justification of the assumption $\phi = 1$ with adiabatic conditions and neutral stability during very hot weather with surface temperature above 100°F.

Dr. Radok asked if u_* could be evaluated directly from a measurement of stress rather than the use of the assumption $\phi = 1$ near the surface. Mr. Spillane asked if it was consistent to use filters to exclude certain wavelengths when using the Fluxatron while no filters were used in measurements of temperature gradients.

Dr. Radok commented on an interesting parallel in the problem of the general circulation of the atmosphere and expressed the opinion that it can be dangerous to be too selective in an investigation of this type.

F.A.P.

20 July 1967

SATELLITE STUDIES OF CYCLONIC DEVELOPMENTS OVER THE SOUTHERN OCEAN

By D.W. Martin

Mr. David Martin, from the University of Wisconsin, presented the results of his year's work at the International Antarctic Meteorological Research Centre, (Melbourne). He opened his talk by pointing out the tremendous potential of meteorological satellites, particularly when applied to meteorological problems in the southern hemisphere. Many thousands of cloud photographs have already been received on an operational basis, but as yet we have hardly