

## JOINT COLLOQUIA

29 May 1968

## THE PLANETARY BOUNDARY LAYER

By W.C. Swinbank

Mr. Swinbank, of C.S.I.R.O. Division of Meteorological Physics, Aspendale, Victoria, introduced his subject by pointing out that it is essential to include boundary layer friction in numerical models of the atmosphere. If a steady state temperature field is proposed without friction, then an infinite number of models is possible because temperature does not determine the pressure field (only the pressure gradient) and it is the pressure field which determines motion. The inclusion of friction limits the number of possible models.

He developed the simple (Ekman, 1905) balance of forces which characterises flow in the oceans, and also Taylor's (1916) extension of this balance to the atmosphere, as the starting point for his own very recent model of the wind profile in the planetary boundary layer.

It follows from the basic equations of motion, that if the observed wind (with components  $u$ ,  $v$ ) blows at angle  $\alpha$  to the pressure gradient ( $A$ ), then the variation of the friction stress with height ( $-\frac{\partial F}{\partial z}$ ) is

$$\frac{\partial F}{\partial z} = A \sin \alpha \quad \dots (1)$$

The constraints which apply are:

- (i) Kinetic energy is conserved in the flow (a less restrictive constraint than the more frequently employed requirement of no accelerations).
- (ii) The shearing stress is in the direction of the wind flow. This is claimed to hold within  $\pm 4$  degrees from observation.

The friction layer was then defined as the layer below the level at which  $\frac{\partial F}{\partial z} = 0$  (and hence  $F = 0$  for geostrophic flow).

An innovation in this treatment was the location of levels in the boundary layer by depth ( $z$ ) below the top of the friction layer. The shearing stress  $F(z)$  at depth  $z$  was expanded as a Taylor series and by neglecting all terms  $\frac{\partial^n \alpha}{\partial z^n}$  for  $n > 1$  (on the basis of observational evidence) it was further shown that  $z$  is proportional to  $\sin \alpha$ .

This predicted dependence of  $\sin \alpha$  on depth below the top of the layer was tested on the Liepzig wind profile data by Mildner (1932) and the result was an almost perfect verification.

A second prediction is that shearing stress is proportional to  $z^2$ . This was tested against the Liepzig data by plotting the shearing stress, computed from quadrature of geostrophic departure, against  $z^2$  and near perfect linear agreement was displayed.

Equation (1) when written in finite difference form provided another test for the model. The shearing stress at any level  $z$  computed from the finite difference equation was compared with the shearing stress computed from the quadrature technique, and very precise agreement resulted again.

Swinbank's theory implies that, given the pressure gradient and wind direction at any two levels in the planetary boundary layer, it is possible to reconstruct the wind profile at all levels. In fact, given four suitable observations (e.g. the wind and pressure gradient at two levels) it is possible to reconstruct the whole pressure field and shearing stress field in the layer. The problem can be presented for computer solution in the form of four simultaneous

equations with four unknown variables. Apart from great simplicity, both in derivation and in application, the hypothesis has the added virtue of relatively few constraints.

There is no reference to stability, no requirement for constant pressure gradients in time, and accelerations are permitted in the flow.

Dr. Sargeant complimented Mr. Swinbank on the amazing simplicity of his treatment. He pointed out the absence of stability as a factor and asked whether its effect was implicit in the theory. Mr. Swinbank held that stability will be reflected in the variation of wind direction.

Dr. Tucker questioned the validity of deducing shearing stresses from the model and using them to test it. Mr. Swinbank re-affirmed that the shearing stresses used in validation were obtained by quadrature of the geostrophic departure.

Dr. Priestley summed up the discussion by repeating the previous comment "amazing" and drew the attention of the meeting to the two theoretical innovations in the treatment, (i) postulating the problem from the top of the boundary layer downwards, and (ii) assuming the shearing stress operates in the direction of the wind. He personally and intuitively would have preferred that the stress operated in the direction of the wind shear, and raised the possibility that this amendment could be tested by computer experiments.

#### REFERENCES

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K. T. M.

26 June 1968

#### INDIRECT OBSERVATIONS OF THE ATMOSPHERE USING MICROWAVES

By D.H. Sargeant

Dr. Sargeant, of the Departments of Meteorology and Electrical Engineering, University of Wisconsin, Madison, (currently working at the International Antarctic Meteorological Research Centre) pointed out that the modern development of numerical forecasting methods has created a need for observations, particularly of the mass field, on a global scale. The "microwave occultation technique" which has been proposed, was first used to estimate surface pressure and atmospheric scale height on Mars and Venus by examining changes in the tracking signal of the Mariner probes as they passed behind those planets and the signal was gradually affected by the planetary atmospheres. For meteorological purposes, more information than surface pressure and scale height is needed and a system would be used which includes a master and one or more slave satellites, the latter returning to the master the signal transmitted by it so that phase comparison could be made and the change in optical path length due to bending and retardation could be determined.