

derived from lysimeter measurements on an alfalfa crop. Evaporation was available from the balance of precipitation, storage and drainage. He did not favour estimation of evaporation from bare soil and crop transpiration together as a single quantity, since transpiration was so critically dependent on stomatal resistance. Measurements of this resistance were made with a "stomatal resistance porometer". Evaporation from the bare soil was regarded as having an upper limit determined by capillary flow or available energy for evaporation, whichever was the more stringent limiting factor. It was found that available energy was usually the control.

Good correspondence was found between values of evaporation obtained from the balance of precipitation, storage and drainage, and from consideration of transport processes within the canopy and the soil (using stomatal resistance measurements for the canopy and energy available for soil evaporation).

In the discussion which followed, Prof. Tanner agreed that lysimeter estimation of evaporation from forest should be feasible as long as drainage measurements were made below the base of the root zone and were not made unrepresentative by horizontal non-uniformities in the soil. He also suggested that eddy correlation and heat balance techniques might be useful. In reference to exchange processes within crop canopies, he stated that transport coefficients were extremely sensitive to turbulence; this would be the subject of further experiments at Wisconsin.

G. A.

30 October 1969

## RECENT ADVANTAGES IN AUSTRALIAN ANTARCTIC GLACIOLOGICAL RESEARCH

By W. F. Budd

In introducing Dr. Budd of the Antarctic Division, Department of Supply, and the Meteorology Department, University of Melbourne, the Chairman of the Colloquium referred to the large contribution to Antarctic glaciology made by Dr. Budd in the last decade.

Dr. Budd first outlined the main topics to be discussed, pointing out that much of the work to be described was the product of a collaborative effort by Melbourne University and the Antarctic Division. The overall concern is with the Antarctic ice cap and the answers to such questions as: what is happening to it; how is this dependent on meteorological processes; and what is its history, particularly in relation to past climatic conditions?

A feature of glaciology is the relative unimportance of hydrostatic pressure and the importance of shear stresses. Ice studies are made on essentially four scales: from the crystal lattice, through polycrystalline sizes, to small and finally large-scale ice caps. Laboratory work is concerned with the first two and is

directed to the determination of the flow law. Strain rates are found to show an approximately linear dependence on stress for small stresses, but increase more rapidly for large stresses, with ice approaching the behaviour of a plastic medium. The equations of motion for an ice cap represent a problem in three dimensions but may be simplified to two dimensions for some studies. After discussion of the various terms in the equation of motion and its formulation in terms of the various parameters of an ice cap (surface slope, bedrock slope, ice depth, etc) Dr. Budd presented a large number of results, both observational and theoretical, firstly for the local region of the Wilkes ice cap and then for the Antarctic ice cap as a whole.

The speaker illustrated the form and the temperature and pressure dependence of the flow law for ice based on a large number of measurements from many sources. Turning to discussion of the Wilkes ice cap, Dr. Budd illustrated the ice surface topography, elevation profiles and velocity vectors along the sides of a triangle with vertices at Cape Poinsett, Cape Folger and the top of the Wilkes ice cap. He then discussed in more detail the profile from the top of the ice cap to Cape Poinsett, pointing, among other things, to an association between ice surface undulations and bedrock topography as determined by radar echo methods. Power spectra of rock and ice slope were also illustrated, some theoretical spectra shown and compared with observation, and comparisons made with the Greenland ice cap.

Dr. Budd went on to discuss various factors affecting the temperature profiles in an ice cap, highlighting the effects of accumulation and surface warming. He worked briefly through the theory of heat conduction in two dimensions and discussed a simple steady state solution. The internal heating effect was illustrated via various temperature profiles through the Wilkes ice cap, and particle paths of snow deposit through the ice cap were shown, confirming that most of the ice of the Wilkes ice cap is younger than 5000 years. It appears that as a net result of ice flow and accumulation, the ice cap is lowering by about 0.5 metre per year at its highest point.

After presenting some results from traverse measurements along the Wilkes-Vostok route, Dr. Budd showed a map of the whole of Antarctica depicting all the traverses made so far, including the South Pole-Queen Maud Land traverse of 1968. He then illustrated in turn, via a series of maps from the Russian Atlas of Antarctica, the bedrock elevation, ice thickness and annual accumulation patterns. This was followed by an annual mean snow surface temperature map and a map of the ice flow lines with the comment that the Ross, Filchner and Amery ice shelves combined, account for almost half the ice drainage from the Continent. Other maps showed various physical characteristics derived from the above data, such as the distribution of balance velocities, surface warming, vertical temperature gradients at the surface, basal temperatures and dielectric absorption.

One interesting map showed the age of the ice at the 90% depth and another at the 50% depth. It was evident that most of the ice of West Antarctica is much younger than that of East Antarctica. Dr. Budd moved finally to discussion of some glaciological studies in the Byrd region, including a discussion of computed bottom melting and freezing rates and the comparison with the observed deep core to bedrock obtained by the Americans at Byrd.

In the discussion which followed, Mr. Gibson asked if, in view of the vast gaps in present knowledge, the speaker would comment on Australia's possible role in future glaciological research. Dr. Budd spoke briefly of the proposals for the

International Antarctic Glaciological Programme (IAGP) - the area of Antarctica concerned being the sector inland from Wilkes, and Dumont d'Urville. In answer to an inquiry as to the accuracy attainable in elevation determination, Dr. Budd replied that Russian scientists claim  $\pm 3$  meters on the basis of geodetic levelling, but errors of the order of  $\pm 100$  meters were to be expected from unclosed barometric levelling at the end of a line inland to Vostok. Future Australian work with geodetic levelling should provide an accuracy of  $\pm 10$  meters.

Dr. Radok mentioned the problem of the katabatic wind and its relation to the low level thermal and pressure fields. He drew attention to the need for a combined meteorological-glaciological study of this phenomenon on the ice slopes and mentioned a preliminary study to be undertaken at Casey.

Dr. Gibbs expressed surprise at the size of the errors in barometric levelling, commented, in relation to earlier remarks by the Chairman, on the great interest shown in glaciological studies by Australian meteorological pioneers such as H.C. Russell, and asked what deductions are possible at this stage on the changing orography of the ice cap. Dr. Budd replied that much of the theory on ice ages and growth and decay of the ice cap is no more than speculation, but certain deductions are possible including that part of the ice of the most central region of East Antarctica is of the order of 200,000-500,000 years old. A final question dealt with the significance to the accumulation pattern of the coastal ablation zone. This zone, he said, is very narrow and only makes a very small contribution to the total mass budget of the Antarctic ice cap.

J. W. Z.