

# ANNUAL REPORT 1966-67

## Division of Meteorological Physics

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## DIVISION OF METEOROLOGICAL PHYSICS

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## I INTRODUCTION

The Division's two principal objectives are a better understanding of the fundamental processes of meteorology and the application of this knowledge to problems of economic importance to Australia. In dynamic meteorology, for example, whilst attention is directed primarily to the basic problems of atmospheric mechanics, prominence is also given to more empirical studies of great practical importance, such as observed association between rainfall and sea surface temperature. In applied meteorology the accent is on agriculture and the efficient use of water. It is in such spheres as these that many of the results and techniques which stem from the Division's major field of interest, atmospheric turbulence and exchange processes, can be readily applied.

## II DYNAMICAL AND SYNOPTIC METEOROLOGY

The General Circulation

(a) An approach to the general circulation of the Southern Hemisphere. The general circulation remains one of the important and difficult areas of meteorology, and in the Northern Hemisphere where there is a relatively good data coverage it has received considerable attention over the past few years. In the south, where large ocean tracts have precluded the building up of a sufficiently dense network of observations, the problems are still more difficult. Recently collaboration with the Geophysical Fluid Dynamics Laboratory, Washington, has been initiated in order to blend expertise in Southern Hemisphere analysis with the more sophisticated dynamical models and computational

techniques and facilities which have developed from Northern Hemisphere work. Such an approach could yield a much better insight into Southern Hemisphere processes, and this collaborative programme is being pursued with optimism on both sides.

(b) Geostrophic Drag Coefficient and Stability.

A series of summer field experiments has been conducted to determine quantitatively the influence of stability on the geostrophic drag coefficient. Under the same wind conditions in the free atmosphere surface stress exhibits a 50-fold variation with stability, as opposed to a 5-fold variation with attainable surface Rossby number - the other principal governing parameter in steady barotropic conditions. For medium values of the surface Rossby number the drag coefficient is revealed broadly as having two dominant values, one applicable to stable, and the other to unstable conditions, with a rapid transition between them through neutral. Under these conditions it was found possible, given broad-scale parameters, such as wind in the free atmosphere, surface roughness and latitude, to estimate the friction velocity to within ten per cent, and the direction of the surface wind to within twenty degrees.

Further experimental work in winter conditions has been planned for the near future to consolidate the results so far obtained.

(c) Momentum Flux in the Boundary Layer, and Accelerations as related to Handover in Scale. Last year's report emphasized the need to explore the scales of motion responsible for transporting vertical fluxes of momentum and energy in the free atmosphere and their connection with those in the surface layer, already extensively studied. Hitherto, the question of the mechanism of vertical momentum flux outside the boundary layer in the west wind belts of the world has received rather little attention, mainly because of the difficulty of making the right kind of measurements. Some preliminary analyses in the Division suggest that the scales of motion

transferring momentum vertically through the top of the boundary layer are largely determined by space and time variability of velocity, and that this is closely linked with typical travelling frontal disturbances.

A field expedition ("Wangara") has now been scheduled in an attempt to measure fluxes of momentum and the various forms of energy, at the 1 km level resulting from motions on the synoptic scale. Vertical velocities will be estimated using a 4-station square of double theodolite wind soundings, 80 km on the side, coupled with radio-soundings of temperature and humidity made at a central point. Observations will be made at hourly intervals and will continue, with but one break, through about 40 days. Besides the hope of deducing reliable estimates of fluxes on the scale mentioned, the data gathered will be valuable for describing the boundary layer under a wide variety of both steady and unsteady conditions, all relevant variables including the surface fluxes being measured. The terrain centred on Hay in New South Wales is level and of uniform roughness for large distances.

(d) Biennial Stratospheric Oscillations South of the Tropics. As reported earlier, observations from the Australian research station Wilkes had revealed the presence of a quasi-biennial cycle of the meridional wind component in the Antarctic stratosphere. Meridional and zonal components and temperature at other Antarctic stations together with winds in the Australian longitude sector of the Southern Hemisphere, have since been analysed for a connection with the quasi-biennial zonal wind oscillation in the tropical stratosphere.

Following the 1963 eruption of Mt. Agung, the oscillations underwent a change in amplitude and phase which, on the basis of the earlier reported reduction in global radiation at Aspendale, might be attributed to the absorption of solar radiation by the dust layer in the stratosphere. There is now

evidence that prior to 1963 the year-to-year variations in the intensity of spring warming in the Antarctic stratosphere were dynamically linked with the amplitude modulation of the annual cycle in middle latitudes. Thus quasi-biennial cycles were found in meridional mass transport during 1958-62, chiefly during spring. Significant correlations between zonal wind and total ozone in the relevant spectral range indicated a biennial rhythm also in meridional-plane circulations. The detailed study of eddy-transport of momentum and heat using eight years' daily observations of wind and temperature at Wilkes, referred to in last year's report, is still in progress.

(e) The Southern Oscillation. The investigations of the Southern Oscillation described in earlier reports have continued. Further verification of the fact that the equatorward meridional wind shear in the upper troposphere in the Southwest Pacific and Australian region is stronger at times of high Southern Oscillation Index has been sought from examination of gradients between Port Hedland and Townsville, and of observed upper winds at these two stations. Both the thickness gradients, and the Townsville winds confirmed this, but no correlation was found in the case of the Port Hedland wind shears.

In 1965/66 it was reported that the zonal component of upper level winds at Canton Island was positively correlated with the Southern Oscillation Index. Furthermore, upper level winds at Canton Island tend to behave in the opposite way to those at Singapore, i.e. an easterly anomaly at Canton Island is associated with a westerly anomaly at Singapore. Correlation coefficients between monthly mean anomalies at 50,000 ft at Singapore and 150 mb at Canton Island were quite big, the largest one - minus 0.65 - occurring during the period December to February. At the same time it was found that nearly all of this opposed variation in December-February, and a considerable fraction of it in other seasons, was associated with variations of the Southern

## Oscillations Index.

There is a suggestion in the literature that the well known 26-month oscillation is propagated downwards, while attenuating, from the equatorial stratosphere into the troposphere. The upper wind observations just referred to were examined for the amplitude and phase of any 26-month oscillation present. The amplitude was found to be small, of the order 1-2 knots, and the phases opposite at the two stations. The opposition in phase indicates that relationships between stratosphere and troposphere are by no means simple.

## Radar Meteorology

(a) Angel Echoes with Dry Cold Fronts. During the past summer, observations continued on anomalous radar reflections known as "angel echoes". These occur in the absence of condensation products which are associated with precipitation and account for the normal echoes seen on the 10 cm surveillance radar screen and mentioned elsewhere in this report. Owing to improved sensitivity of the radar and the installation of a range-height indicator coupled with a spell of unusually dry weather, the number of well defined angel echoes observed has increased considerably. Pronounced echoes in the form of unbroken lines and bands, mainly over Port Phillip Bay, were found to be closely connected with the passage of dry cold fronts and to be a result of strong humidity gradients.

To try to relate frontal kinematics to echo movement, serial pilot balloon ascents have been made and data from six years' observations of cold fronts and sea breezes applied to a statistical treatment of refractive index change at ground level. This and other research suggests that at some fronts the gradient region of refractive index is bounded on its down-wind side by a "shock" zone. The nature and configuration of this zone (in section, appearing as a thin crescent with convex side uppermost) accounts for the greatly enhanced power reflection coefficients

associated with it. Moreover, the concave underside of the zone will, by focussing, result in even further aerial gain in the same way as convective bubbles in the atmosphere, investigated extensively overseas, give rise to dot angels.

So far, a single run of measurements has been made with a fine structure temperature recorder of high resolution at rooftop level, to determine the sharpness of the initial frontal change. From a recorded temperature fall of  $3^{\circ}\text{F}$  in  $1/16$ th sec, the thickness of the shock zone is estimated to be of the order of 10 cm. Measurements of the frontal eddy structure of refractive index by airborne refractometer are planned for the near future.

(b) Other. Recurving tropical cyclones from the north-west tend to provide continental areas south of the Tropic of Capricorn with useful rainfall. This occurred with tropical cyclone "Elsie", January 1967, in large parts of the interior including the Nullarbor Plain and parts of South Australia. A canopy of high cloud extended east and southward from the cyclone and covered most of Victoria, but with insufficient development of middle and low cloud there, only very light rain fell and that at widely scattered places. Radar observations at Aspendale showed an unbroken and persistent layer echo in the middle troposphere varying in thickness from 500 to 3,000 m and sometimes having a double structure. The layer extended generally to the limit of the range-height indicator (110 km). A study of this hitherto unknown type of layer echo showed that it was embedded in a deep layer of initially very dry air associated with strong vertical wind shear below a jet stream. The slope patterns of the layers are compatible with the calculated trails of snow flakes generated at cirrus level, descending through the wind shear and evaporating before reaching melting level. Radar observations of this kind further our understanding of rainfall inhibiting processes and of the wider problem of drought.



A large body of data on radar rain echoes has been statistically analysed in relation to geography and upper winds, with a view to presenting a radar climatology of the Melbourne area. Of particular interest is the movement of echoes in relation to wind at various levels. It has been shown that echo displacement is usually most closely related to the wind at about 8,000 ft, implying rather large air motions relative to echoes at other levels. A higher frequency of echoes than might normally be expected has been revealed over the ocean outside Port Phillip Bay: over land, the echo frequencies bear a rough resemblance to annual mean isohyetal patterns. Statistical relationships which should have an application in short term weather forecasting are being computed.

A study of microwave propagation across Port Phillip Bay was continued during the summer months. The intensity of radar reflections from a pile light (range approximately 20 miles) was measured and examined in the light of prevailing weather conditions. Analysis of the results is in progress.

### General

The extensive seabreeze data of the earlier Coonalpyn Downs expedition, which provided a complete circulation, temperature and humidity picture of moving seabreeze fronts, has been processed. It shows that the midsummer seabreeze normally begins to accelerate inland about midday, and frequently penetrates up to 100 miles. In its decaying stages it can be looked on as a moving vortex with its axis horizontal. It has considerable temperature contrast in the early stages, but this declines markedly as it moves inland: later in its life it can often still be identified as a discontinuity in humidity. Superimposed on the broader circulations is much smaller scale variability, which frequently obscures the overall picture unless care is taken to remove it by averaging a number of cases.

Further examination has been made of monthly mean anomalies, including those of wind at 200 mb, during the 1964-65 drought, to see if the drought period could be characterised by any consistent circulation anomalies. Whilst there was a tendency for pressures to remain low over the subtropical South Pacific during the period, this was not so in all months, and so far no really satisfactory association with any pressure or circulation anomaly has been established. The work continues.

Previously reported work in the Division has shown that changes in sea surface temperature off the east coast of Australia are closely linked with large scale variations in rainfall in adjacent areas. More detailed studies, or extension to other coasts, are prohibited by the lack of appropriate sea surface temperature records. Accordingly, plans to measure sea temperature in co-operation with the Bureau of Meteorology and the C.S.I.R.O. Division of Fisheries & Oceanography have been drawn up. Specifications for the sensing buoy, telemetry and receiving station are complete, and the first prototype buoy nearing completion. It is proposed to set up a pilot scheme of 6 to 8 stations for a period, and in the light of the experience gained, to establish a network of stations around the Australian coast.

The geographical distribution of rainfall and low level wind divergence during known periods of locust swarming in eastern Australia has formed part of a collaborative study with the C.S.I.R.O. Division of Entomology and the Locust Research Centre, England. The purpose of this study is to determine whether locust swarming in this country is influenced by large scale circulations, especially the low level convergence, as has been found to be the case in Africa.

### III UPPER ATMOSPHERE STUDIES

#### Ozone

Observations of the total amount of ozone and of its vertical distribution by the "umkehr" method have

continued at Darwin, Brisbane, Aspendale and Macquarie Island, in collaboration with the Bureau of Meteorology and the Antarctic Division of External Affairs. To further our understanding of the synoptic distribution of ozone in the middle latitudes of the Southern Hemisphere the present network of ozone observing stations has been expanded by installing a Dobson spectrophotometer at Hobart. This instrument, recently calibrated at Aspendale, went into operation in June 1967: training in observational techniques has already been given to local Bureau of Meteorology staff at Hobart. The instruments at Macquarie Island and Brisbane were also recalibrated this year.

The regular weekly ozone soundings using the Brewer-Mast ozone sondes mentioned in earlier reports have continued. The planned series of daily soundings made at Aspendale during October 1966, together with the intensive series of releases from Aspendale, Hobart, Mt. Gambier and Adelaide during the same period were carried out successfully with the co-operation of the Bureau of Meteorology and the Weapons Research Establishment. Analysis of the results is in hand.

Reference has been made in earlier reports to the surface ozone measurements, employing Emherts type equipment, made at Aspendale and Macquarie Island. It is now planned to extend this work to provide a continuous record of ozone throughout the 24 hours as opposed to the single daily value currently available. To this end an instrument of the bubbler type is being developed.

Night spectrophotometer measurements using the moon as a light source have been made at Darwin ( $12.5^{\circ}\text{S}$ ), Hay ( $34.5^{\circ}\text{S}$ ), Aspendale ( $38.0^{\circ}\text{S}$ ) and Hobart ( $42.8^{\circ}\text{S}$ ) and the results compared with the day time values. Using the 'AD' method to compute ozone amounts, no significant difference is found between the two: however, if the calculations are made using individual wavelength pairs (A, C and D) and the haze corrections omitted, the night values usually exceed the day values. This implies that

what appears to be an increase in night ozone is in fact a result of increased large particle scattering at this time.

Contrasting with this are the results of middle latitude observations using the B( $\lambda$ 3088/3291) wavelength pair: these showed an apparent decrease in ozone at night, implying enhanced radiation at this wavelength. At first this was tentatively attributed to OH emission (at  $\lambda$ 3088), but it is now thought the emission near  $\lambda$ 3090 from the Herzberg O<sub>2</sub> band associated with weak aurora effects could equally well be the answer. The work continues.

Vertical ozone distributions obtained from balloon borne sondes over the last two years reveal significant differences from year to year. In the winter and spring 1965 ozone concentrations in the 18-30 km layer was 20-30% higher than in the same period in 1966, indicating substantial differences in the transport mechanisms for these two years. Preliminary analysis reveals a three dimensional picture of what other workers have termed an "ozone river" trailing downwards from the warm core of a stratospheric low. Detailed analysis of this and other examples is expected to provide further insight into ozone transport processes and stratospheric-tropospheric exchange.

From the analysis of surface ozone measurements made at Aspendale so far, it has been observed that the yearly maximum in surface ozone occurs about late spring, i.e. at the same time as the maximum  $\beta$  activity in rainfall at Aspendale. This suggests that the transport mechanisms operating between stratosphere and troposphere are similar in both cases.

At the surface certain relationships have been found to hold between ozone and wind velocity depending on the season. In spring and autumn monthly ozone figures deviate negatively from the monthly means when winds are southerly and westerly, respectively. In winter an east wind is associated with a positive deviation in ozone whilst in summer a deviation of the same sign occurs in strong anti-cyclonic situations.

## Radioactivity and Volcanic Dust as Upper Atmosphere Tracers

Routine measurements of the  $\beta$  activity in rainfall at Aspendale, begun in 1958, have continued. The results show a strong seasonal effect with a maximum in late spring (see Fig. 1), coupled with an increase following each major series of atomic bomb tests. In terms of a diffusion transport process operating between the equator and pole, this implies a meridional transfer coefficient of the order  $3 \times 10^9 \text{ cm}^2 \text{ sec}^{-1}$ . Related information is provided by observations of volcanic dust from the Bali eruption of 1963, discussed later in this report.

The large increase in  $\beta$  activity in late 1966 is attributed to the French tests in the South Pacific between July and October of that year. However, the tests were small scale ones and their effect on the overall level of activity had virtually disappeared by early 1967. This is consistent with current views of a short tropospheric residence time of the order of three weeks, compared with a stratospheric residence time of months or years - see Fig. 1. Results obtained at Aspendale from the French test series are in agreement with the much wider assessment of fall-out over Australia carried out by the Atomic Weapons Test Safety Committee.

Analysis has now been completed of the  $\text{Be}^7$  concentrations in stratospheric air samples obtained during late 1965 with the co-operation of the Balloon Launching Station at Mildura, Victoria, and the U.S. Air Force Weather Reconnaissance Flights at East Sale and Avalon, Victoria. When compared with the known production rate of  $\text{Be}^7$  in the stratosphere by cosmic rays, these data confirm the feasibility of using  $\text{Be}^7$  as a tracer to study stratospheric transfer processes.  $\text{Be}^7$  is produced predominantly in polar regions in contrast with other tracers such as ozone, radioactive fallout and volcanic dust which, for the Southern Hemisphere have been predominantly of equatorial origin. With the experience gained it is proposed to put

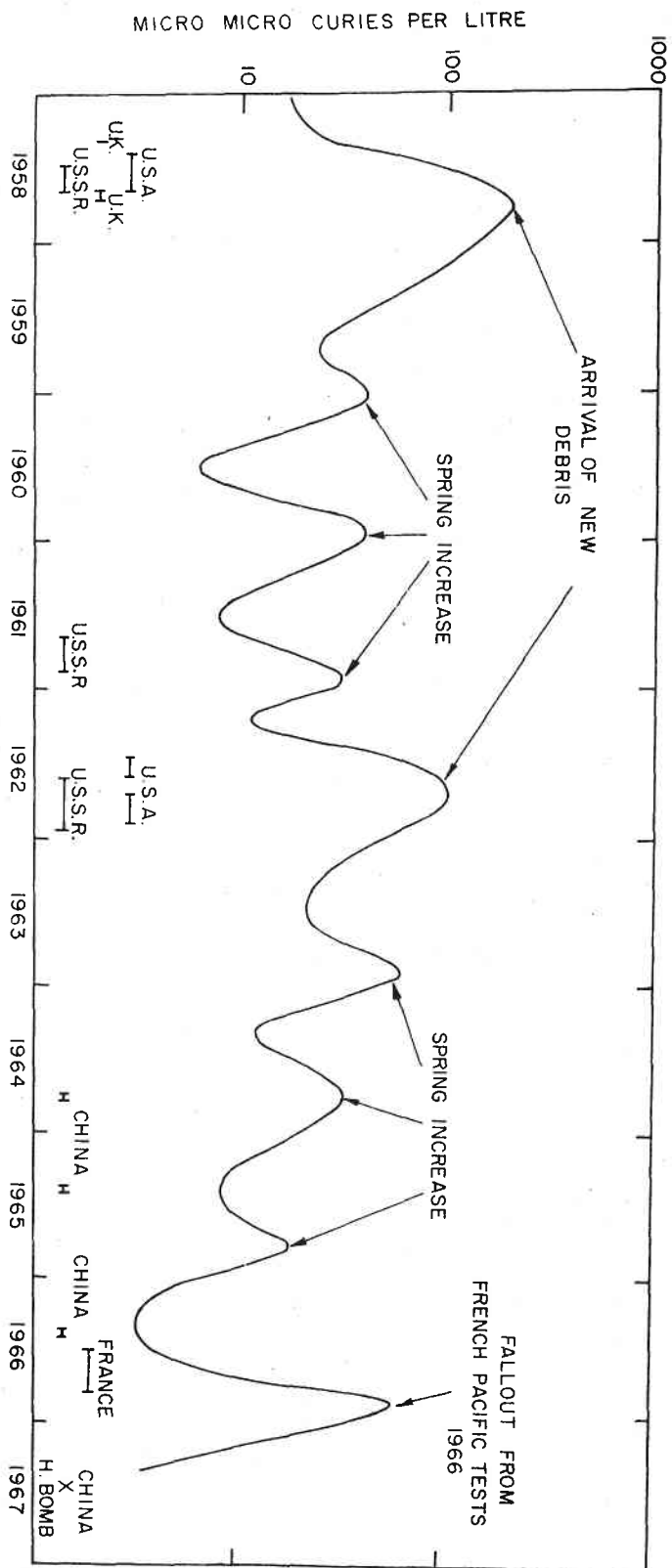


Fig. 1: Radio-active content of Melbourne rainwater since 1958.

some of the work on a routine basis and to expand the programme to include other tracers produced by cosmic rays.

To gain further experience in the field of radioactive tracers, an officer of the Division spent some time at the Argonne National University, Illinois, U.S.A., examining the feasibility of using naturally occurring radioactive thoron and radon gas as atmospheric tracers in situations of mesoscale dimensions, particularly raining clouds. The radioactive daughters  $Pb212$ ,  $Pb214$  and  $Bi214$ , in the radon and thoron decay schemes were detected by gamma-ray spectrometry in a series of rainfall samples. On the basis of a simple mathematical model, the results indicated that the scavenging of aerosols by raining clouds was of the order 1% to 5% per minute.

Further evidence of stratospheric transport processes has been gained by the completion of the global radiation survey aimed at assessing the spread of volcanic dust from the Bali ( $8^{\circ}S$ ) eruption of 1963. The analysis, a continuation of the work referred to in last year's report, clearly shows that the Southern Hemisphere received a much greater influx of volcanic dust than the Northern Hemisphere. In both hemispheres seasonal effects are very obvious, with a maximum occurring at middle latitudes in mid-winter and at the poles in late winter to spring. The poleward progression of the maxima is the same at all latitudes greater than  $20^{\circ}$ , and amounts to about 40 cms/sec. This however is not meant to necessarily imply a poleward air velocity of this rate, since eddy diffusion is generally regarded as playing a very significant part in the meridional transport process. Another feature of this analysis is that the amplitude of the maxima (amount of dust per unit area of earth's surface) is found to be constant with latitude.

The Division has continued to operate air sampling equipment as an agency for the U.K. Atomic Research Establishment global survey of radioactive

fallout. Other air samples are being sent to the Argonne National Laboratory.

#### IV GENERAL MICROMETEOROLOGY

The preliminary analysis of observations from the micrometeorological expeditions during 1961-64 at specially selected sites at Kerang and Hay, referred to in previous reports, has now been completed. The results clearly indicate equality of the transfer mechanism for the vertical transport of heat and water vapour, both differing from that for momentum; the transfer coefficients for the former being greater in lapse conditions. Since it is expected that the extensive body of data obtained from these expeditions will be of value to other workers, the figures are to be published shortly as a Technical Paper. Analyses of the data from various points of view will be published as separate papers.

Reference was made in last year's report to the development of the Fluxatron. This instrument, which is designed to be an improved, simplified version of the Evapotron, has recently been used in a number of investigations involving the measurement of heat flux. During the early part of 1967 it was installed at the C.S.I.R.O. Research Station, Katherine, Northern Territory, for use by members of the Division of Land Research in their investigations of the growth of Townsville lucerne. Plans are well advanced for the incorporation of the Fluxatron technique into the measurement of water vapour and momentum transfer.

The simple bulk aerodynamic formula, for evaluating from meteorological observations the evaporation (or heat flux, or shearing stress) over lake or sea, has been generalized to apply when the atmosphere is thermally stratified. The new formula has been tested by applying it to the well known Lake Hefner (U.S.A.) 1950/51 data, in which the daily evaporation determined from water budget measurements is the basis for comparison. Using the traditional simple formula, the estimated daily



evaporation (sum of 3-hourly values using observations at 8 m height), relative to the measured evaporation, has a standard deviation of 21 per cent; using the new generalized formula, this spread is reduced to 16 per cent. The reduction indicates (since the squares of uncorrelated errors are additive) that the effects of thermal stability which are absorbed by the new formula amount to 14 per cent, or over 40 per cent of the variance. This figure represents the net daily effect of thermal stratification; the effects over shorter periods during the daily cycle must often be considerably greater, but there is no way of checking these from the data.

A relevant factor is the height of observation - the smaller this is, the smaller is the influence of thermal stratification. However, it is not generally practicable to make reliable shipboard measurements at heights of less than a few metres. As an example of the magnitudes involved, if the air at a height of 8 m is 3 deg C warmer than the water, and the wind speed is  $5 \text{ m sec}^{-1}$ , then the estimated evaporation is reduced by 30 per cent.

The generalized formula will find application in evaluating lake evaporation, and in estimating sea-air interchange over areas subject to a systematic sea-air temperature difference. Preparation of a set of curves for practical application, showing the thermal stability factor over a wide range of conditions, is now being completed.

Analysis of a series of temperature fluctuation measurements at a height of 2 m, recorded in inversion (evening) conditions at the Edithvale site, has been completed. The results show two distinct regimes, for Richardson numbers ( $Ri$ ) respectively less than or greater than a critical value lying between 0.15 and 0.2. When  $Ri$  is less than the critical value, the fluctuations are typically turbulent, with r.m.s. magnitude (taken relative to the mean temperature gradient) comparatively large and decreasing as the critical value of  $Ri$  is approached. When  $Ri$  exceeds the critical value, the behaviour is intermittent and unpredictable -

sometimes the temperature is quite devoid of fluctuations, at other times it exhibits variations which may be wave-like or turbulent; however, the relative r.m.s. magnitude remains small and apparently unrelated to the actual value of  $R_i$ .

The spectrum exhibits corresponding behaviour. With  $R_i$  in the lower range, it has a form characteristic of turbulence, close to the minus  $5/3$  power law over the high frequency portion. With  $R_i$  in the upper range, the form of the spectrum is indeterminate in individual cases, but on average tends to approximate to a minus 1 power form, indicating a uniform spectral distribution per unit proportional range of frequency.

Last year's report referred to the difficulty experienced by solar astronomers owing to shimmering of the image - a result of the strong temperature fluctuations in the lower atmosphere over land surfaces heated by sunshine. Measurements of temperature fluctuations over the sea made in previous years had suggested that an observatory on an island in a lake would experience much better conditions. Accordingly, an exploratory programme of observations of temperature fluctuation intensity and simultaneous seeing conditions along a horizontal path was conducted in collaboration with the C.S.I.R.O. Division of Physics, the site chosen being the Prospect Reservoir near Sydney. Spectral analysis of the temperature fluctuation records and image movements has been completed for a selection of these runs and a report is in preparation.

#### Gust Structure of Strong Winds

The use of higher voltages for the overland transmission of electric power and the consequent increase in tower height and cable span presents designers with problems on the response of transmission lines and towers to the gusts experienced during gales. Existing knowledge of the lateral extent of gusts being very meagre, a line of 5 suitable anemometers spaced 30 m apart was installed

at a height of 15 m above open grassland in February 1967. Since then, strong winds have been disappointingly infrequent but sufficient records have been secured to give useful information. Correlation and co-spectral computations are well advanced.

The microstructure of temperature and humidity close to the ground is being studied by a capacitor refractometer technique, in which variations in the dielectric constant of the air are detected by a fast-response system. An extensive series of records of temperature and humidity fluctuations were obtained during a field study, together with measurements of sensible heat, net radiation, wind and temperature profiles. The data have been programmed for analysis by computer. It is possible that this technique will be employed to study the humidity and temperature structure of thermals using glider-borne equipment.

## V AGRICULTURAL METEOROLOGY

### The Lysimeter Installation

Twelve large lysimeters (2 square metres in area, 1.1 metres deep and 6 tons in weight) and filled with either water or soil carrying a crop, are maintained at Aspendale. Weighing continuously and automatically to one part in 140,000, they have been used over the past few years to study evaporation from a natural surface, initially pasture. The purpose of the programme has been to check the validity of various types of evaporation formulae which make use of readily available meteorological parameters such as radiation and water vapour pressure.

Particular attention has been paid to formulae of the combination type, i.e. those based on both aerodynamic and energy conservation principles. In the application of such formulae to non-potential conditions, it is necessary to include moisture conductance terms in the several components of the

soil-plant-atmosphere system. At present these are not easily measured, and must be related to readily ascertainable parameters. Current investigations seek a quantitative measure of the dependence of these conductances on the moisture status of soil and vegetation, on the aerodynamic roughness of the crop surface, and on the wind speed. Investigations on the effect of wind-speed on the atmospheric or "external" conductance were initiated over the pasture. Subsequently, potato crops have been planted to investigate the effect of the aerodynamic roughness of a crop.

Evapotranspiration rates below the potential occur when soil water is restricted, but they have also been found to occur with the soil at field capacity, providing the evaporative demand is high. This is a result of a resistance to water movement within the plant itself. For example, a demand equivalent to a rate of  $1 \text{ mm hour}^{-1}$  from a free water surface appears to be greater than the maximum rate of flow attainable through potato plants, even from wet soil.

Departures from the potential rate, whether they result from restricted soil water supply or from high evaporative demand, have been allowed for in a combination type evaporation formulae by incorporating an "internal conductance" coefficient. Further investigations have related this conductance, over periods of a day or less, to variations of plant properties which reflect plant water stress, such as turgidity and water potential, and over longer periods (days or weeks), to variations of soil moisture.

The hydraulic-pneumatic lysimeter referred to in earlier reports and designed as a simple and rugged but accurate instrument suitable for network purposes, has been operated during the past season and been compared with the precision balances mentioned above. There was no evidence of drift and agreement between the two types was good, scatter in the records of the hydraulic lysimeter being equivalent to a few hundredths of an inch of water. During this time

the experimental area was sown to a row crop (potatoes) and since it is necessary to preserve the ratio of crop cover to soil area in the lysimeter, a rectangular soil container was employed. The instrument is now in commercial manufacture and it is hoped that before long a suitable print out recorder will be available.

### Transpiration Reduction

Glass-house trials to assess the feasibility of chemical treatment of plant foliage to reduce transpiration loss have continued.

Three chemicals have been tested - a particular type of O.E.D., an oxyethylene high fatty alcohol compound; P.M.A. (phenyl-mercuric acetate), a metabolic inhibitor which induces stomatal closure; and silicone fluids, which consist of dimethylpolysiloxane chains, the viscosity of the fluid being determined by the length of the chain. All three chemicals reduced transpiration from potato plants growing in soil maintained at field capacity, by some 25-30%, but the particular O.E.D. used appeared less effective than the other two materials. The reduction in transpiration has been achieved without any statistically significant reduction in yield.

Other potato plants, some of which were treated, were grown in soil which, starting at field capacity, was allowed to dry out over a period of time. The transpiration rate of the untreated plants fell gradually at first, then quite sharply as the plants became subject to severe water stress. On the other hand the treated plants showed an immediate reduction in their transpiration rate. The water thus conserved enabled this lower rate to be maintained and it did not ultimately fall as low as that of the untreated plants.

The main value of the treatments appears to lie in the delay of the onset of severe water stress till later in the drying cycle. The high transpiration rates of summer and the low ones of winter appear to

be equally reduced whilst the anti-transpirants themselves are effective over a wide range of concentrations: O.E.D.  $10^{-5}$  to  $10^{-4}$ ; P.M.A. 1% to 5%; and silicone viscosities of 100 to 12,500 centistokes.

### Blue Mould in Tobacco

The work previously reported was continued during the 1966/67 growing season. Forecasts obtained from the Commonwealth Bureau of Meteorology are used, in conjunction with a theoretical model previously developed in the Division, to decide whether or not a test crop shall be sprayed. The results are then compared with those obtained from test crops sprayed according to other programmes, or not at all. Results to date indicate that good protection may be obtained by this method but the general incidence of the disease has been so low during the period of these experiments that firm conclusions are not yet possible.

The work is being carried out jointly with the Victorian Department of Agriculture at the Tobacco Research Station, Ovens, with financial assistance from the Tobacco Advisory Committee.

### General

Modifications have been made to a pilot-model of an instrument designed to record continuously evaporation from a natural surface and known as an energy partition evaporation recorder (E.P.E.R.). The instrument automatically makes the measurement and carries out the calculation which involves a modified form of the well-known Bowen ratio method of determining evaporation. Field trials have revealed good agreement with lysimeter evaporation for hour-long periods throughout the day. Further developments are under way and an application for a patent has been lodged.

During the past three years, this Division has collaborated with the C.S.I.R.O. Irrigation Research

Laboratory, Griffith, in making measurements at Coleambally, N.S.W., to evaluate the effect of irrigation on climate. The measurements have now been provisionally terminated, and processing of the data is proceeding. Conclusions will be reported when this analysis is completed.

Temperature and humidity measuring equipment has again been lent to the State Department of Agriculture in connection with an investigation into the incidence of Brown Rot in peaches.

## VI RADIATION

Recently a stocktaking was made of the observation and calibration programmes of the radiation group. These represent responsibilities largely of an external nature, being concerned with the maintenance of standards for international and national purposes, and with the running of a central observatory programme and an instrument calibration service. A statement of these programmes is provided at Appendix A, and the notes which follow here concern items of current detail.

The comparison of four different types of net pyrradiometer, conducted under the auspices of the C.I.M.O. Working Group on Radiation Instruments for General Use, has been completed. Hourly records for twelve months of the net radiation recorded by the four instruments have been processed and await analysis by W.M.O. authorities.

The Xenon arc lamp intended as a short wave radiation source for calibrating radiation instruments has been installed and the associated power supplies almost completed. It is anticipated that testing of the light source and a mirror-drum scanning device designed to improve uniformity of the irradiation of the target area will be commenced shortly.

Since net pyrradiometers are instruments designed to respond to both solar (short wave) and

terrestrial (long wave) radiation, they must be calibrated in both wavebands. Until recently a liquid filled black body was used as a long wave source, but this has been superseded by an electrically heated instrument, in which the internal wall temperature is uniform to within  $\pm 0.1^{\circ}\text{C}$ .

There has been some delay in completing the monochromator equipment, referred to in last year's report, and designed to measure the distribution of energy in the solar spectrum. However, the work is nearing completion and it is expected that calibration and recording will go ahead shortly.

Radiation data measured from an R.A.A.F. aircraft has continued, and computation of the results is in progress. This will provide values of net radiation including the upward and downward short wave components over a wide range of latitude, land and sea surface, and cloudiness.

A solar radiation measuring instrument has been made available to the Australian National Antarctic Research Expedition for installation at Macquarie Island. Assistance has been given to the Department of Botany, Melbourne University, in measuring the output of a spectral radiation source.

In radiation work it is often desirable to have an instrument mounting which will accurately follow the sun's path throughout the year. To this end a "sun tracker" is currently under construction.

Technical enquiries, some trivial and some requiring detailed attention and/or experimental work are received at the rate of about 80 a year. For example, a request was recently received from the Meteorological Service of the United Arab Republic to detail equipment required and suggest a programme of work for a proposed National Radiation Centre at Helwan, Egypt.



## VII MISCELLANEOUS

The computation and data processing group has continued to assist in a wide variety of investigations.

The routine analysis of ozone data at the various ozone stations has been greatly facilitated by the computation of tables giving the solar zenith angle for every minute throughout the year at each station.

Other work carried out by the group during the year includes the following: treatment of data from the Hay and Kerang expeditions for profile investigations; calculation of the effect of atmospheric thermal stratification on transfer over water surfaces; correlation analysis to determine the cross wind scale of turbulence; statistical analysis of stratospheric winds and temperatures and their spectral relationships with ozone; processing of temperature and humidity fine structure data; evaluation of evaporation over crops; the estimation of ozone both from ozone sondes and by the "umkehr" method; the spectral analysis of vertical wind fluctuations measured from an aircraft; the seasonal analysis of Antarctic upper wind data; and the processing of airborne radiometer measurements to assess the distribution of radiation under varying conditions of terrain and weather.

The service provided by the Division in its capacity as an accredited testing authority of the National Association of Testing Authorities, in the fields of low speed anemometry and atmospheric radiation instruments, continues to grow. Anemometer calibrations show an increase of almost two-thirds over the average annual total for the past three years, whilst certificates for radiation instruments are up by almost one-third over last year's total. A calibrating service is also provided for heat flux plates.

Further development of the "Sumner" Long Period Recorder has continued, it now being possible when measuring water level to record two independent levels on a single chart. A long period recording snow gauge has also been constructed commercially, and two such instruments are to be installed in the mountains of Northern Victoria. Since its inception, about 400 recorders have been manufactured and, as a result of a continuing demand, a comprehensive illustrated Maintenance Manual has been compiled to assist users when servicing their instruments in the field.

To meet a growing need for an anemometer capable of measuring the low air speeds involved in problems arising out of the storage and transport of fruit, drying of various products, etc., a relatively simple and robust instrument has been designed. Tests of several specimens having proved satisfactory, a provisional patent application is being lodged. The anemometer, which is entirely non-mechanical, has numerous advantages, the most important being good sensitivity in the  $0.1$  to  $3 \text{ m sec}^{-1}$  range, omnidirectional operation (in the horizontal plane), a time constant of about 1 minute, thus smoothing out short period fluctuations, and an output suited to potentiometric recorders. Tests on the stability of calibration characteristics have not yet proceeded for long enough for this to be thoroughly established, but in the light of previous experience little difficulty is expected.

A number of observations of vertical air velocity component obtained by the C.S.I.R.O. Division of Radiophysics from an aircraft flying at heights between 30 and 5,000 ft, are being analysed in terms of simultaneous ground-based observations of various meteorological parameters made by this Division. Spectra and frequency distributions of the vertical component have been calculated and are being correlated with stability and other atmospheric variables. This work is being done in collaboration with the Department of Meteorology, University of Melbourne.

In collaboration with the C.S.I.R.O. Division of Applied Chemistry and the Department of Meteorology, University of Melbourne, temperature soundings from an aircraft and upper winds by pilot balloon were obtained in the vicinity of five control bush-fires lit by the Western Australian Forests Department for the protection of forests. Results are being analysed. It is hoped that this study will contribute to the better understanding of the convection processes and to the predictability of fire behaviour in various synoptic weather situations.

The new wind-tunnel mentioned in last year's report has been completed and found to give a velocity distribution across the large working section (4' 1" wide  $\times$  2' 3" high) constant over the greater part within  $\pm 0.5\%$ . The wind speed range in this section is 0.1 to 19 m sec<sup>-1</sup> and in the smaller working section (2' 3"  $\times$  2' 3") in tandem, 0.2 to 35 m sec<sup>-1</sup>. Variations in fan speed are achieved by a Reeve's Vari-speed drive unit incorporating a conventional type 10 h.p. electric motor. Wind speeds below 3.5 m sec<sup>-1</sup> are obtained by the aid of a throttle system with a venetian blind type action.

A low torque anemometer of lightweight construction has been designed for use when accuracy at low wind speeds is required. It comprises a photo transistor pulse mechanism (which reduces friction at this stage to the minimum), and inbuilt amplifier. These instruments are now produced commercially, a number having already been sold.

To assist the State Electricity Commission in an investigation of the behaviour of overhead electrical transmission lines under various weather conditions, a special wind vane designed for commercial production and having an electrical output suitable for use with a potentiometric recorder has been developed.

During the year the need arose to devise a simple system which would permit the launching of

radio sonde type balloons from rough ground under windy conditions. Accordingly, a lightweight portable winch embodying a variable friction release has been designed.

#### VIII ACTIVITIES AND PERSONALIA

Meteorology is inherently international by nature, and continues to grow rapidly in this respect. Members of the Division have continued their association with various organizations, both national and international, which have been formed to deal with problems of Antarctic Research, Dynamic Meteorology, Ozone, Evaporation, Hydrology, Special Radiation Instruments and Observations, Plant Injury and Air Pollutants, Oceanic Research and Space Research.

During the year Dr. C.H.B. Priestley, Chief of Division, was elected to the Fellowship of the Royal Society, and was awarded the Symons Memorial Gold Medal. The latter is the senior award of the Royal Meteorological Society and is made for distinguished contributions to meteorology.

Dr. Priestley and Mr. W.C. Swinbank attended the 11th Pacific Science Congress in Tokyo in August, 1966. Later at Kyoto both presented papers at an International Symposium on Boundary Layers and Turbulence including the Geophysical Applications.

In March, 1967, Dr. Priestley left for Geneva where he attended the Third Session of the U.G.G.I. Committee on Atmospheric Sciences and the Fourth Session of the W.M.O. Advisory Committee, of which he was elected Chairman. In this capacity he attended the 19th Session of the Executive Committee of the W.M.O. in May of the same year.

As a result of overseas invitations, Mr. Swinbank obtained twelve months' leave of absence from the Organization as from January of this year. He is spending five months at the University of Hawaii as Visiting Professor, followed by a four months visit in the same capacity to the University of California, Los Angeles.

Following a year's attachment to the Geophysics Fluid Dynamics Laboratory of the U.S. Weather Bureau, Washington, where he worked on new approaches to the problem of the general circulation in the Southern Hemisphere, Mr. R.H. Clarke returned to Australia early this year.

Also returned from the U.S.A., Mr. B.B. Hicks, in December, 1966, completed an extended visit to the Air Resources Laboratory of the Environmental Science Services Administration, Washington, D.C., and the Argonne National Laboratory, Illinois. The essential purpose of his visit was to examine the feasibility of using radon and thoron gases as radioactive tracers in the atmosphere.

Granted a year's leave of absence, Mr. I.C. McIlroy left for Cairo early this year to take up a temporary appointment as W.M.O. expert in Agrometeorology at the Meteorological Institute for Research & Training.

Sponsored by the W.M.O., a Regional Seminar in Agricultural Meteorology was held in Melbourne in December, 1966: Mr. McIlroy and Dr. D.E. Angus both presented papers.

The course of lectures in Micro-meteorology at Melbourne University, which for some years has been given by Dr. Angus, whilst still forming part of the advanced Meteorological Syllabus, can now also be taken as part of the final year Physics Course.

Mr. R.J. Taylor's secondment as Senior Research Fellow to the Department of Meteorology, University of Melbourne, terminated in March, 1967.

Preparatory to setting up an Agrometeorological network in Iraq, Mr. R.J. Sakka from the Iraq Meteorological Service spent four months with the Division studying the application of micro-meteorological techniques to agricultural problems.

## APPENDIX A

The Observation and Calibration Programmes of the  
Atmospheric Radiation Group1. Introduction

At the fourth meeting of the World Meteorological Organization (W.M.O.) Regional Association V at Wellington, N.Z., during February, 1966, it was decided that this Division should be the Regional Radiation Centre for Region V, as well as being the National Radiation Centre for Australia. A Regional Radiation Centre is defined as a centre for international comparisons of radiation instruments within the region, maintaining standard instruments necessary for this purpose. The conditions it should satisfy include among others, the possession of standard instruments in prescribed quality and number, with necessary ancillary equipment and the means to check and maintain it, as well as having sufficient technical staff to provide for continuity, including a qualified scientist with wide experience in radiation.

The National Radiation Centre serves as a centre for the calibration, standardization and checking of instruments used in the national network of radiation stations and maintains instruments sufficient for this purpose.

It is also desirable that a National Radiation Centre should maintain high quality observations of the main radiation quantities. In this connection the W.M.O. Regulations provide that at principal radiation stations the observing programme should include continuous recording and publication of hourly totals of global solar radiation and of sky radiation, regular measurements of direct solar radiation, and records of sunshine duration.

It is from the above requirements that the radiation group's programmes of observation and calibration derive, and these are now described in more detail.

## 2. Observational Programme

At present continuous recording and publication of hourly totals is carried out for global solar radiation, sky radiation, net radiation (day positive and night negative), ultra-violet radiation and duration of sunshine. It is proposed to add shortly direct radiation, on the same basis. The recording and integrating of the signals are done by automatic data logging equipment developed within the group. This prints hourly totals of each quantity which are then transferred to punched cards to be processed by CDC computer. The printed results are transmitted monthly, via the Commonwealth Bureau of Meteorology to the Main Geophysical Observatory of the U.S.S.R. at Leningrad, who publish data for the World Network. The results are also available to other interested bodies and persons as required.

As to accuracy of the measurements, Part VI of the I.G.Y. Instruction Manual states that in a continuous record of the radiation from sun and sky an accuracy of  $\pm 5\%$  represents the result of good and careful work. The aim within the group is to improve on this figure by at least a factor of 2, and in fact comparison of current measurements for global radiation with others made independently a few miles away shows agreement to within 1%.

## 3. Calibrations

In addition to fulfilling the calibration requirements of the W.M.O. for a National Radiation Centre, the Division is a Registered Laboratory of the National Association of Testing Authorities, Australia, for the calibration of instruments to measure radiant flux, and is the only such laboratory in Australia. This registration requires that, in addition to the short wave radiation standard which meets W.M.O. requirements, a long wave standard should be held, for calibrating net pyrrometers and pyrgeometers. This standard is a low temperature black body cavity, designed and constructed within the group, giving

a radiation flux of intensity known to better than 0.5%.

Some years ago an improved polythene shielded net radiometer was developed in this Division and patented. There are at present three commercial licensees under the patent, and the calibration of their products is one of the major calibration tasks of the radiation group. A wide variety of other instruments varying in size from 1 cm diameter to over 3 m long is submitted for calibration and testing by users throughout Australia.



## IX PUBLICATIONS

- Angus, D.E. (1966) - Closed-circuit television at conference. Aust. J. Sci., 29 : 124-125.
- Angus, D.E., and Hill, R.H. (1966) - A multi-purpose digital thermometer. CSIRO Conference on Instrumentation for Plant Environment Measurements, Aspendale, 1966 (Publ. The Society of Instrument Technology, Australia) : 40-41.
- Berson, F.A. (1966) - The mass and heat budgets of the atmosphere over the Antarctic Plateau (with particular reference to spring). International Antarctic Meteorological Research Centre Tech. Rep. No. 6.
- Berson, F.A. (1967) - Spring-warming transfer processes in the lower Antarctic stratosphere. Tellus, 19 (2) : 161-173.
- Berwick, P.D. (1966) - A pneumatic lysimeter. CSIRO Conference on Instrumentation for Plant Environment Measurements, Aspendale, 1966 (Publ. The Society of Instrument Technology, Australia) : 24-25.
- Clarke, R.H. (1966) - Turbulence and the detailed structure of a subtropical jet stream. J. Atmos. Sci., 23 (5) : 516-530.
- Collins, B.G. (1966) - Determination of the cosine response of pyranometers. J. Sci. Instrum., 43 : 837-838.
- Collins, B.G. (1966) - Silicon solar cell radiation integrator. CSIRO Conference on Instrumentation for Plant Environment Measurements, Aspendale, 1966 (Publ. The Society of Instrument Technology, Australia) : 13-14.

- Dyer, A.J. (1966) - The Evapotron - An eddy flux instrument for measuring natural evaporation. CSIRO Conference on Instrumentation for Plant Environment Measurements, Aspendale, 1966 (Publ. The Society of Instrument Technology, Australia) : p. 39.
- Dyer, A.J. (1966) - Artificial radio-activity, ozone and volcanic dust as atmospheric tracers in the Southern Hemisphere. Tellus, 18 (2) : 416-420.
- Dyer, A.J. (1967) - The measurement of eddy-fluxes in the lower atmosphere. CSIRO Symposium on the Collection & Processing of Field Data, Canberra, 1966 (Publ. Interscience Publishers) : 55-59.
- Dyer, A.J. (1967) - Global fall-out aids meteorological research. Electronics Australia, 28 (11) : 8-11.
- Dyer, A.J., Hicks, B.B., and King, K.M. (1967) - The Fluxatron - A revised approach to the measurement of eddy fluxes in the lower atmosphere. J. Appl. Meteorol., 6 (2) : 408-413.
- Funk, J.P., Deacon, E.L., and Collins, B.G. (1966/II) - A radiosonde radiometer. Pure & Applied Geophysics, 64 : 212-219.
- Hill, R.H. (1966) - An attachment for the Sumner long term recorder that integrates a radiometer output. J. Sci. Instrum., 43 (11) : 829-830.
- Kulkarni, R.N. (1966) - The vertical distributions of atmospheric ozone and possible transport mechanisms in the stratosphere of the Southern Hemisphere. Q. J. Roy. Met. Soc., 92 (393) : 363-373.
- Kyle, T.G. (1966) - A crystal radiometer with FM output. J. Sci. Instrum., 43 (10) : 750-753.

- Kyle, T.G. (1967) - Frequency shift radiometer.  
CSIRO Conference on the Collection & Processing of Field Data, Canberra, 1966  
 (Publ. Interscience Publishers) : 61-65.
- Kyle, T.G. (1967) - Absorption of radiation by uniformly spaced Doppler lines.  
Astrophysical Journal, 148 : 845-848.
- Kyle, T.G. (1967) - An error in the <sup>0</sup>Angstrom pyrheliometric scale. Tellus, 19 (2) : 240-242.
- Kyle, T.G. (1967) - A crystal pyrradiometer.  
Pure and Applied Geophysics, 66 : 126-132.
- Maher, F.J. (1967) - The multivibrator bridge of temperature measurement. J. Sci. Instrum., 44 : 531-534.
- McIlroy, I.C. (1966) - An energy partition evaporation recorder (E.P.E.R.). CSIRO Conference on Instrumentation for Plant Environment Measurements, Aspendale, 1966  
 (Publ. The Society of Instrument Technology, Australia) : 42-44.
- Penman, H.L., Angus, D.E., and van Bavel, C.H.M. (1967) - Microclimatic factors affecting evaporation and transpiration. Chap. VIII, Irrigation of Agricultural Lands (Agronomy No. 11), ed. R.M. Hagan, H.R. Haise, T.W. Edminster (American Society of Agronomy, Madison, Wisconsin, U.S.A.) : 483-521.
- Pittock, A.B. (1966) - A thin stable layer of anomalous ozone and dust content.  
J. Atmos. Sci., 23 (5) : 538-542.
- Priestley, C.H.B. (1967) - Microclimates of life.  
Science Journal, 3 (3) : 67-73.
- Priestley, C.H.B., and Troup, A.J. (1966) - Droughts and wet periods and their association with sea surface temperature. Aust. J. Sci., 29 (2) : 56-57.

Shepherd, W. (1966) - The haymaking process.  
7th Annual Conference Grassland Society of  
 Victoria, 1966 : 10-14.

Shepherd, W. (1967) - Transpiration and internal  
 moisture relations of the potato plant.  
Australian Potato Agronomy Conference,  
 Healesville, 1967. 4 : 7-9.

Shepherd, W. (1967) - Micrometeorology of the potato  
 crop. Australian Potato Agronomy Conference,  
 Healesville, 1967. 4 : 5-6.

Sumner, C.J. (1966) - The multi-purpose battery-  
 operated long-term recorder. CSIRO Conference  
 on Instrumentation for Plant Environment  
 Measurements, Aspendale, 1966 : 44-45.

Sumner, C.J. (1966) - A sunshine sensing device for  
 long period recording. Q. J. Roy. Met. Soc.,  
 92 (394) : 567-569.

Sumner, C.J. (1967) - Maintenance Manual for Mk. II  
 Sumner Long Period Recorder. CSIRO Div. of Met.  
 Physics (Melbourne).

Swinbank, W.C. (1967) - Air-sea interaction.  
Symposium on the Meteorological Results of the  
 IIOE, Bombay, July 1965. (Publ. India Met.  
 Department) : 75-84.

Taylor, R.J. (1966) - Microclimate and  
 instrumentation. Australian Plant Pathology  
 Conference, Toowoomba, Qld., 1966, 3 : 11-16.

Taylor, R.J., Bridley, S.F., and Webber, R.T.J. (1965)  
 - The effects of irrigation and rolling on  
 nocturnal air temperatures in vineyards.  
Agricultural Meteorology, 2 (6) : 373-383.

Webb, E.K., and Coulman, C.E. (1966) - Daytime  
 seeing and thermal structure in the lower  
 atmosphere. Nature, 212 (5057) : 58-59.

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|                              |  |
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