# ANNUAL REPORT 1969-70

# Division of Meteorological Physics

Commonwealth Scientific and Industrial

Research Organization, Australia

Melbourne

CONTENTS

# DIVISION OF METEOROLOGICAL PHYSICS

# ANNUAL REPORT

# 1969 - 1970

## I INTRODUCTION

The Division of Meteorological Physics came into being in 1946 with the establishment of a small Section in temporary buildings in Melbourne. Later, a permanent location was found at Aspendale, some 18 miles south of the City, and it is here that the administrative offices and laboratories are presently situated. In 1969, the Commonwealth Meteorology Research Centre was formed. This unit has its own offices in Melbourne and a summary of its objectives and achievements will be found in Section IX of this Report.

Unlike many other meteorological organizations, the Division has purely research responsibilities and is not required to engage in operational activities. Broadly, its aim is a fuller understanding of the basic physical processes which control weather and climate. From the outset a major field of study has been micrometeorology (including turbulence), since it is at the earth/air interface that the essential energy transformations take place. Turbulence in micrometeorology also has important economic applications, embracing evaporation, plant/environment interaction and atmospheric pollution. Radiation studies are of comparable importance and are now receiving more attention.

Atmospheric dynamics of larger scale is also prominent, since this is at the heart of the weather process, as well as being an area in which the advent of weather satellites and high speed computing machines are opening up new prospects of very real advancement.

## II DYNAMICAL AND SYNOPTIC METEOROLOGY

### The Boundary Layer

It will be recalled that the Wangara experiment set out to determine broadly two things: firstly, the scales of motion responsible for transporting the vertical fluxes of momentum, heat and water vapour at the top of the boundary layer, and secondly, the way in which they could be linked to those in the surface layers. The data from this experiment has now been thoroughly scrutinized and will be published shortly. At a time when interest in boundary layer problems is running high, it is hoped the material will be of interest to many workers in this field.

So far analysis of the data has

(a) led to a good description of the boundary layer under a variety of conditions;

(b) improved our understanding of the behaviour of the layer in respect of relationships between surface stress, heat flux and evaporation on the one hand, and wind, temperature and humidity at the top of the layer on the other.

From these results and in the context of numerical models of the atmosphere, it has been possible to propose a new treatment of the boundary layer - which already has been incorporated into an overseas model and into an Australian one.

It is well known that wind speed and direction over land sites tend to vary systematically with time of day. Within 100 km of a continental coastline, land and sea breezes are responsible for very marked diurnal variations, but further inland other factors are involved. Among the more important are topography which can produce mountain and valley winds, and the diurnal mixing cycle in the lowest kilometre or so, resulting from surface heating. The latter mixes momentum, heat and water vapour vertically during the day, but at night effective contact with the earth's surface is cut off. As a

result, at low levels (up to 16 m at Hay in winter) the maximum wind is experienced by day due to mixing with air aloft, whilst in the higher layers the downward drain of momentum results in a day-time wind minimum followed by a midnight maximum, as the pressure forces acting to restore the balance overshoot the mark.

Whilst the slope of the experimental site at Hay amounted to only 2½:10,000, it had a measurable influence on the daily surface wind pattern. In the afternoon it was responsible for an up-slope wind of 1 m $sec^{-1}$, which turned to the left during the night (as a result of the earth's rotation), becoming a down-slope wind near day-break. The mixing cycle has a stronger effect, producing at an altitude of several hundred metres a daily wind oscillation of some 2 m $sec^{-1}$.

In trying to understand the reasons for the variability of the low level wind, an obvious starting point is a spectral analysis of the three components of wind velocity. This has been applied to the Hay wind data, when observations were made at hourly intervals for the whole 40 days of the expedition. The periods available ranged from a few hours upwards, and it was found that most of the variability resided in the longer periods, corresponding in size to weather map disturbances.

Not surprisingly, there is a detectable contribution from the inertial frequency due to the rotation of the earth (a period of about 21 hours at Hay). This shows up in the components but not in the overall wind speed, which has a strong diurnal mode. The most important information obtained concerns the flow of vertical angular momentum associated with the larger scales of motion. This is quite definitely upward, i.e. in the reverse sense to that required to replace the loss through drag at the earth's surface. In other words, it is the very large and very small scales of motion which are responsible for redressing the balance.

Numerical experiments so far indicate that our treatment of the boundary layer is very successful.

Nevertheless, at least two difficult problems remain. The first involves the large scatter obtained when similarity theory is applied to atmospheric observations made in stable conditions, suggesting that factors neglected in the theory are often important; the second, to the role of inversion height in unstable conditions. A closer study is being made of these two questions with a view to obtaining a better understanding of the effects of turbulence in diabatic conditions.

## Long Term Variations in the Stratosphere

The thought of being able to make accurate extended predictions on the course of the weather has attracted many meteorologists over the years. Unfortunately their attempts, which often employed statistical methods, met with little success and it is only in the recent past - with the introduction of numerical dynamic models of the general circulation - that hope has been revived again.

In an attempt to disentangle the major causes of the long term variations in the general circulation, appropriate orthogonal band-pass filters have been developed and applied to the long term records of wind and temperature in the lower stratosphere as well as total ozone, which are now becoming available. In this way it is possible, for example (albeit indirectly), to examine the long term response of the layer to fluctuations in the sun's ultra-violet radiation, and to diffuse radiation from clouds. At present, emphasis is being placed on the response of the lower stratosphere to the sun-spot cycle (period 11 years) and a terrestrial cycle (period 6 months) which affects cloudiness in the tropical belt. Results so far indicate that the variation with latitude is in the right sense even when the response is very weak (but statistically significant).

## General

The advent of the modern computer has also made possible more satisfactory model studies of medium scale phenomena, land and sea breezes, katabatic and

anabatic winds, convective systems, bush fires, tropical cyclones, and so on. Recently, a model sea breeze was constructed with the object of studying it under varying conditions of prevailing wind, terrain, temperature structure, wind heat input, and latitude. It is anticipated that an account of the results will appear in the next report.

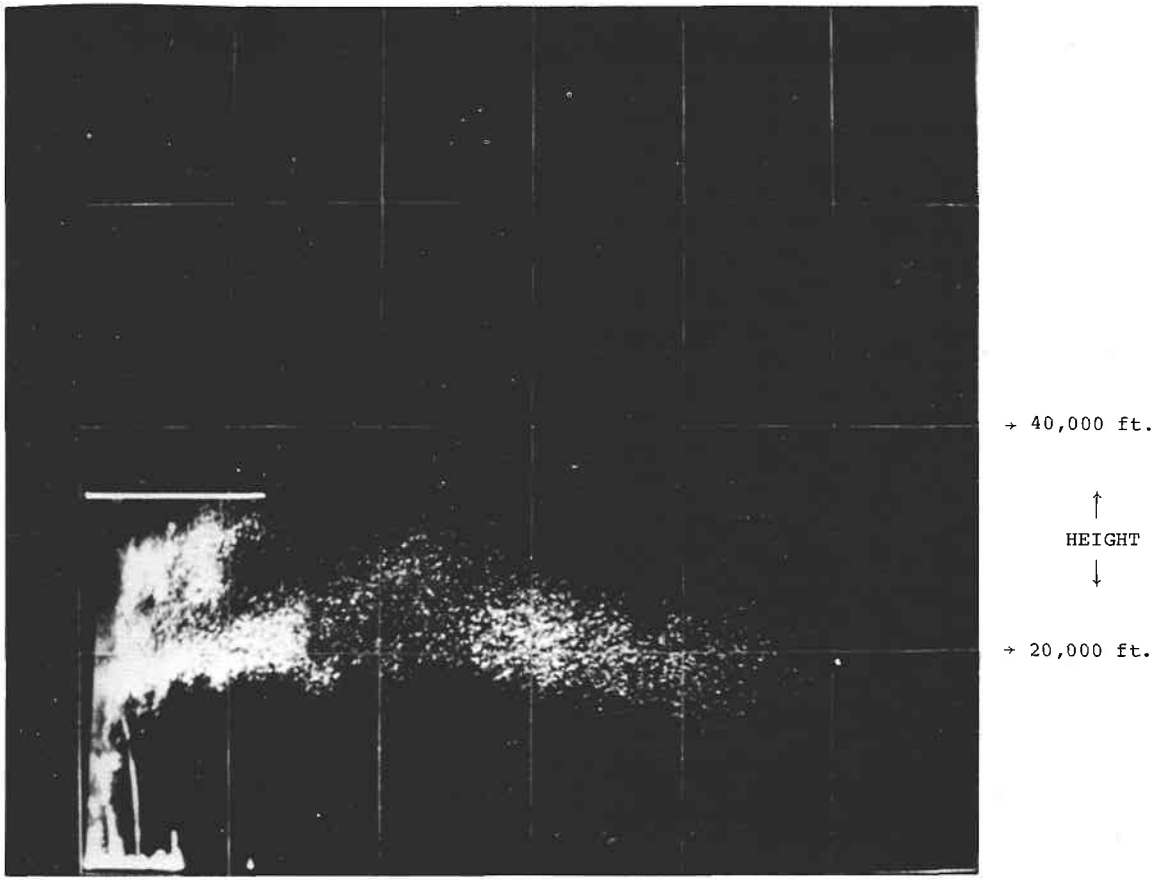
The "Morning Glory" is the name local residents give to a spectacular cloud formation which occurs along the coast of the Gulf of Carpentaria in spring and summer. The clouds appear about day-break in the form of a long straight line (or several parallel lines) moving from the east at moderate speed in an otherwise cloudless sky. Their passage is preceded by a calm followed by a gusting of the surface wind and has been explained in the literature as a land breeze or katabatic wind. A numerical model, which examines the dynamics of a shallow layer of chilled air at the earth's surface, has been able to reproduce almost all of the known features of the "Morning Glory". It is shown to be closely related to the undular bores experienced in some rivers, and is essentially a propagating hydraulic jump forming on a shallow katabatic air flow from the highlands of the Cape York Peninsula.

## III RADAR METEOROLOGY

### Multiple Band Echoes from a Clear Sky

"Radar tends to provide observations of this kind by accident rather than by design." This can well be said of unstable gravity waves occurring in a visually clear atmosphere, and meteorologists are looking for well documented radar case studies of this phenomenon.

Recently, as a result of an alert radar operator on routine weather watch duties, the Bureau of Meteorology were able to notify us of anomalous echoes then being received on their 10 cm radar from the Port Phillip Bay area. The Division's S-band




Ice-crystal fall-out

radar was brought into operation to display a detailed structure of the echoes. They were made up of multiple bands orientated in the direction of the wind as well as crosswind patterns, and occurred in the presence of a strong wind surge beneath a frontal inversion. They resulted from a particular type of boundary layer perturbation - so called unstable Goetler vortices, developing over a concave surface. Upstream from the vortices, rapid evaporation of low level stratiform cloud bore evidence of boundary layer separation.

## Ice Crystal Fallout and Convective Storms

Another distinctive type of echo seen on the screen of the Division's S-band radar is illustrated opposite page 7 . This is somewhat unusual in that it arises from the presence of a widespread layer of ice crystals falling out from the uppermost parts of a convective storm. This phenomenon is of particular interest since ice crystals are a potential source of natural cloud seeding material and a knowledge of their propagation will lead to a better understanding of the triggering action on down-wind clouds.

Field work has already included a series of observations at Brisbane using the Bureau of Meteorology's radar there. A statistical treatment of the observations obtained has yielded information on the growth and movement of thunderstorms - especially the kind of severe storm which moves across the large scale wind flow, and is therefore difficult to predict for a particular location such as an airport. From this work also has come an indication of the incidence of hail associated with severe storms and an average dimension of the region in which turbulence is likely to be encountered.

## Dry Weather Fronts and Bird Movements

The physical interpretation of echoes seen on a radar is still a major problem in certain circumstances. Between 1966 and 1968 in dry summer conditions at Aspendale, there were many occasions when a diffuse "line echo", emanating from a visually clear part of the sky, was observed on the

Division's 10 cm radar screen. Although it was noticed that the echo was associated in some way with a dry cold front, ornothologists suggested that flocks of swifts might account for the phenomenon. Co-operation was therefore sought from the Victorian Bird Observers Club and the Victorian Ornothologists Research Group in an attempt to decide the issue.

A study of all the available data for the period in question revealed the following: although swifts (sometimes in large numbers) do in fact tend to forage in the warm dry air immediately ahead of a front, their location did not coincide with the source of the echoes. It was subsequently found that the explanation lay in an entirely different area - atmospheric refraction. Associated with fronts are small scale refractive index fluctuations, and it is the back-scattering effect of these which are responsible for the echoes seen on the screen.

Radar Rain Echoes

An analysis has been completed of data relating to over 5,000 rain echoes observed on the Division's S-band radar over a four-year period. The echoes have been statistically related to surface and upper wind, temperature and humidity, and have been shown to move with, but slightly to the left of, the mean wind in the layer 4-12,000 ft.

Radio soundings showed that:

(a) the lapse of temperature with height resembled a moist adiabat up to 12,000 ft, and

(b) the absolute humidity decreased rapidly with height, whilst the wind increased only slowly.

A simple numerical model has been set up which reproduces many of the features observed, and it is expected that further work along these lines will lead to better ways of formulating poorly understood processes such as entrainment into shower clouds.

# IV THE UPPER ATMOSPHERE

## Radioactive Tracers

Previously we have outlined the extrapolation of our early studies of the radioactivity of rain water into the investigation of specific radioactive elements in air. Emphasis has been placed on the importance of beryllium-7, a naturally-occurring radionuclide, produced largely in the polar stratosphere by the interaction of cosmic rays and air molecules. By monitoring the concentrations of Be-7 and comparing them with those of fission products, very useful information can be deduced on the nature of the transport processes in the stratosphere. At present, insufficient data is available to allow a precise statement of the results, since a long record is necessary before seasonal studies become statistically meaningful.

However, a preliminary investigation shows that there is a slight difference between the annual cycles in Be-7 concentrations and those of the fission products. Since the latter are essentially of equatorial origin and the former of polar origin, this implies a latitude variation of the horizontal transfer coefficients. This behaviour is consistent with some recent models of the general circulation which allow enhanced transfer from the equator to the poles in late winter.

To confirm our understanding of the Be-7 production processes, a second cosmic ray-produced isotope, S-35, was measured. The concentration ratio of the two isotopes was found to be very close to that predicted by theory.

A report of some further work in this field will be found in Section VI QUALITY OF THE ENVIRONMENT.

## Ozone

The measurement of ozone, at the surface or in the stratosphere, serves three important functions.

Ozone is a particularly important tracer. Formed in the upper atmosphere, it transfers slowly to the lower stratosphere where, being shielded from photo-chemical destruction it can be used to indicate circulation systems.

Ozone has a strong absorption band in the ultra-violet and the energy so absorbed plays a vital part in the radiation balance of the atmosphere.

At lower levels ozone is formed as a by-product of man's industrial activities and is a part of the general pollution problem.

Although most of the "weather" is generated outside the stratosphere, the circulation at this level can be used as a guide to the processes taking place below. For this reason a good deal of effort is devoted to understanding the circulation processes in the stratosphere of the Southern Hemisphere - where the pattern of events is very different from that in the north. To provide the raw data for this sort of work, a network of observing stations across Australia has been established. Currently, they comprise Aspendale, Darwin, Brisbane, Hobart, Perth and Macquarie Island, the latter in collaboration with the Bureau of Meteorology and the Antarctic Division of the Department of Supply. Each station is equipped with a Dobson spectrophotometer and routinely measures total ozone in a vertical column throughout the depth of the earth's atmosphere. In addition, at Aspendale a weekly measurement is made of the vertical distribution of ozone, both indirectly by the Umkehr method and directly by balloon borne sondes of the Mast Brewer type.

Much has already been done in relating the behaviour of ozone to the general circulation of the stratosphere on a seasonal, annual, biennial, and even solar cycle basis. The next logical development has been to examine the dynamics of the 100 km level (where events are under direct solar control) connecting this via the intermediate levels to the circulation in the stratosphere. For this

Preparing an ozone sonde prior to release

purpose an airglow photometer has recently been constructed, employing in part, equipment borrowed from the Antarctic Division. The instrument measures the intensities of the green and red lines (respectively $\lambda$ = 5577Å and 6300Å) in the night airglow. Analysis of some observations obtained by workers in Adelaide as well as others made by Divisional staff at Deniliquin (180 miles north of Melbourne) has only just started, but already tentative values for the eddy diffusion coefficient and vertical and horizontal velocities at the 100 km level have been obtained.

Above 40 km it was noticed that changes in ozone concentration occurred about the same time throughout the world - implying a solar effect. The 4 to 5 year cycle in ozone concentration which has emerged is being examined in relation to events occurring at lower levels.

It has been observed that the ozone amount over Brisbane is greater than that over Pretoria and is situated mostly in the lower stratosphere. This first evidence of the longitudinal variation of ozone in the Southern Hemisphere is an indication of the differences in the strength of the meridional mixing in these two sectors of longitude.

In polar regions the stratospheric circulation is dominated by a winter cyclonic vortex which breaks down in late winter and early spring to be replaced by an anti-cyclonic circulation. Both in the Arctic and Antarctic this final breakdown is preceded by waves on a planetary scale which dramatically change the temperature structure (up to 40°C) and ozone content of the stratosphere. During the spring of 1967 the Macquarie Island area was affected by these waves, the effect being observable on some occasions as far north as Aspendale. To take a closer look at this phenomena the "Macquarie Island Planetary Wave Experiment" (M.I.P.W.E.) has been planned for August, 1970. Simultaneous ozone soundings will be made at Macquarie Island, Hobart (Tasmania), Aspendale and Invercargill (N.Z.). The operation is being carried out with the assistance of the Antarctic Division of the

Department of Supply, the Commonwealth Bureau of Meteorology and the New Zealand Meteorological Service. The phenomena will assume practical as well as scientific importance with the advent of commercial air navigation at these levels.

Weather satellites are being used increasingly to probe the atmosphere, and it is to be expected that they will ultimately provide the means of obtaining much of the data from the ocean areas on which weather forecasting depends. In the case of ozone, for example, the measuring technique employed by satellites is similar to that used in the (ground-based) Umkehr method. With this in mind, same day comparisons of sonde and Umkehr derived vertical distribution of ozone have been made and revealed apparently systematic differences as between seasons, years and stations. The causes are being looked into as they may have a bearing on the accuracy, resolution and representativeness of some of the atmospheric parameters derived from satellite observations, e.g. vertical distribution of ozone and temperature.

As with many meteorological elements, an important aspect of the work is the budget of ozone on the global scale. Broadly speaking, ozone is generated in the upper stratosphere and destroyed at the earth's surface. By measuring profiles and deducing the fluxes, near the surface, the destruction rate at the ground can be obtained. In describing how ozone is transferred to the earth's surface a "rate constant" is introduced. This is defined as the ratio of ozone destruction per unit area to the concentration at the surface and - rather surprisingly - remains unchanged from place to place over a given type of surface. So far measurements have only been made over grass and soil, but there are plans to repeat the observations over snow and ocean areas.

The results of a comparison of the near surface concentrations of ozone, dust and radon will be found in Section VI QUALITY OF THE ENVIRONMENT.

In 1969 NASA's Nimbus III satellite "Iris"

carried a downward-looking spectrometer to measure the infra-red spectra of the atmosphere, and from this to evalute the vertical distribution of ozone. To check the accuracy of the computed ozone concentrations, a series of ozone soundings by balloons were made from Aspendale and arranged to coincide with the passage of the satellite.

To improve the measurement of surface ozone concentration, a sensitive integrator has been designed and constructed to provide a continuous integration of the concentration and a print-out of the accumulated total, at 30-minute intervals. A photon counter to measure the u.v. emission from airglow has been constructed. The sensing head is a photomultiplier producing a small-amplitude current spike of very short duration for each incident photon. The occurrence of these is very irregular, varying from coincidence to intervals of several hundred microseconds. A discriminator-amplifier-divider chain was constructed to accommodate these random bursts and record them on a counter. A selection of sampling times is available.

## V MICROMETEOROLOGY

### Air-Sea Interaction

The interaction between the ocean and the atmosphere has been little understood in the past, but the increasing use of numerical forecasting methods makes it imperative that the problem be faced urgently. This is particularly so in the Southern Hemisphere where the ocean areas occupy a relatively large proportion of the global surface.

The Division has long been studying the interactions between air and surface over land, and more attention is now turning to the parallel processes over sea, which for a number of reasons are more difficult. Accessibility and the need for a suitable platform from which to work are among the practical problems.

During October 1969 an experiment was performed

using an offshore oil rig (provided by ESSO Pty. Ltd.) in Bass Strait, as a basis of operation. The basic intention was to study the form of the Ekman wind spiral in the lower atmosphere by using pilot balloons, backed up by micro-meteorological measurements made near the sea surface. Although it was originally thought that the latter measurements might be adversely affected by the bulky structure of the oil rig, it turned out that satisfactory eddy-flux measurements can be obtained. This favourable outcome, coupled with the extreme stability of the rig, has interesting possibilities for the future.

A second approach is being made using a floating buoy devised originally by a visitor to the Division - Dr. P. Frenzen of the Argonne National Laboratory. The buoy is designed to have much more stability than a simple surface floating one, by providing it with an underwater drag plate and a low centre of gravity. Some recent calculations indicate that the instrumentation used with the buoy requires still greater stability.

With this in mind, a new instrument - the Near Isotropic Flux Turbulence Instrument (NIFTI) - is being developed to measure eddy fluxes over the sea. Measurements are made of the mean square deviation of horizontal wind velocity and temperature in a narrow region of the spectrum centred on a frequency of about 0.4 cycles per sec. This relatively high frequency is chosen to avoid distortion of the data which would otherwise result from the motion of the buoy itself.

The underlying principle of NIFTI rests on the general belief that the spectral properties of the atmospheric turbulence are unique functions of the frequency, normalised with respect to height $\bar{z}$ and wind speed $\bar{u}$ and a stability parameter $(z/L)$. Research here and overseas has made considerable progress towards establishing the validity of the concept, and the numerical values of the constants involved. Once on a firm footing, the way will be open to determining eddy fluxes via spectral measurements. Ultimately, it is hoped to relate

eddy fluxes with the bulk air-sea differences in wind and temperature. Whereas over land we have been concerned with surfaces of fixed geometry (i.e. roughness), over sea there is an added complexity in that this in itself is a variable depending on the interactions which are under study.

## The Flux-Gradient Relationship for Momentum and Its Variation with Stability

During March, 1970, an expedition was made to Gurley, N.S.W., to investigate the flux-gradient relationship for momentum in the constant flux layer, and its variation with stability. Similar attempts in the past have been somewhat inconclusive because of uncertainty regarding the correct value of $u_*$, the friction velocity. Previously, this had been estimated from the low-level wind, but this approach led to criticisms centred around the question of stability effects. Technical improvements in the Fluxatron, an instrument designed to measure eddy fluxes, have now made it possible to determine $u_*$ directly by the eddy correlation technique.

The Gurley experiment was conducted on a 20,000 acre wheat farm (Gurley Station) immediately after ploughing. Measurements included wind and temperature profiles, net radiation and ground flux, and eddy-flux determinations of vertical transfer of momentum and heat. The analysis of the data was carried through in terms of the Monin-Obukhov universal functions for heat and water vapour ($\phi_H$ and $\phi_W$ respectively) with the stability parameter $z/L$.

The results lay within the stability range $0.01 < -z/L < 1$, and the $\phi_M$ values were confirmed to be quite different from those for $\phi_H$ and $\phi_W$, which in earlier work had been shown to be equal. The quantity $\phi_H/\phi_M^2$ was very close to unity throughout this range of stability, implying that Ri was very nearly equal to $z/L$. As an empirical expression of the results, the relationships

$$\phi_M = (1 - 16\ z/L)^{-\frac{1}{4}},$$

$$\phi_H,\ \phi_W = (1 - 16\ z/L)^{-\frac{1}{2}}$$

were found to agree with the data to within a few per cent. These equations therefore serve as an approximate statement of the experimental findings, within the above range of stability. There are a number of reasons why they should not be regarded as capable of extrapolation to regions of higher instability - where there is already good evidence that quite different laws are required.

In conventional measurements of eddy flux of momentum, inadvertent tilting of the sensor can give rise to significant errors - which derive from long period fluctuations in u. In the Fluxatron technique, the latter are automatically filtered out and higher quality results thereby achieved.

Diffusive Adjustment

In many practical applications of micro-meteorology, measurements must be made when only a limited fetch is available over the surface of interest (e.g. lake or irrigated land). The question then arises: how are the basic flux/profile relationships for a diffusing quantity, such as heat or water vapour, distorted as a result of incomplete adjustment to the underlying surface? A theoretical solution to this problem, at present restricted to conditions of near-neutral thermal stability, has been worked out. In contrast to earlier theories, it takes account of the purely molecular (non-turbulent) diffusion in a thin layer adjacent to the surface. It thereby avoids an artificial "blow-up" of the solution which otherwise supervenes in the case of neutral or unstable conditions. The results are being prepared in graphical form for ready practical application.

Thermal Convection

Through thermal convection, vast quantities of heat and water vapour are transported upwards from the earth's surface into the atmosphere - an essential step in the chain of meteorological interactions which produce the "weather". It is important to gain a thorough understanding of the convection process and its quantitative

relationships. Much has already been learnt about convection in the so-called surface layer (heights up to 30 m or so), where measurements can readily be made with instruments mounted on masts. However, the nature of the coupling between the surface layer and the larger-scale thermals which extend up to heights of hundreds or thousands of metres remains to be investigated. As a step in this direction, a series of measurements were conducted over flat terrain at Hay, N.S.W., in February, 1970. Mean quantities, and the turbulent fluctuations of wind components and temperature, were measured at several heights up to 32 m, on masts. On the ground, the pattern of surface flow associated with thermals was recorded using an array of seven instruments measuring wind speed and direction, placed at intervals of 100 m across wind. Gliders flying at heights of 1000 to 3000 ft were used to plot the tracks of thermals, and, on some occasions, to measure their temperature excess and updraft. Analysis of the results is under way.

General

An important aspect of our understanding of atmospheric turbulence in the near-surface layers is concerned with the spectral properties of the fluctuating quantities. This knowledge is basic to such projects as the NIFTI programme (referred to above) which seeks to evaluate eddy fluxes by measuring the intensity of turbulence in a narrow spectral band. A number of recordings at a height of 4 m were made at the Division's Edithvale site, of u (horizontal wind component), v (vertical wind component) and T (temperature). These were digitised and, using the Fast-Fourier technique, power spectra of u, w and T determined together with the cross spectra w:u and w:T. At the high frequency end, all spectra were broadly consistent with the Kolmogorov 5/3 law for the inertial sub-range. The w-T spectra clearly demonstrated the expected movement of the spectrum peak towards lower frequencies with increasing instability.

The rate of viscous dissipation of turbulent kinetic energy is a useful parameter for

characterising the intensity and structure of the turbulence under various conditions. New information on how this parameter varies as a function of height and atmospheric stability is being obtained from a number of vertical velocity spectra, obtained from an aircraft, flying at heights up to 5000 ft. The analysis is not yet complete, but it has been shown that there is a decrease in dissipation rate with increasing height and stability. The decrease with height appears to be less rapid in summertime over grassland - where the turbulence is probably mainly thermal in nature - than it is in winter-time over forest, where mechanical influences predominate.

One of the problems which faces numerical modellers of the atmosphere is the partition of net radiant energy as between the turbulent fluxes of heat and water vapour over a land surface. Some past records have recently been examined and results to date show that under certain conditions the evaporation rate can be expressed as a consistent fraction of the net radiation. The conditions are that the surface be saturated and that the effects of advection be neglected - as they often are in this particular context. How long the evaporation remains unchanged, and how quickly it declines to zero afterwards, are quantities which must be expected to vary from site to site, and this aspect is receiving further study.

## VI QUALITY OF THE ENVIRONMENT

### Turbidity from Radiation Measurements

The attenuation of the direct solar beam by the total particulate content of atmospheric pollution is of interest in itself and also provides a means by which this pollution content can be determined. The measurements involved are fairly straightforward and the method has been used at Aspendale - weather permitting - to determine atmospheric turbidity for the past five years. Recently, equipment has been developed to give

continuous records whenever conditions are suitable.

The Department of Meteorology, Melbourne University, is assisting by making similar observations at the University site near the central city area. Further equipment has been ordered so that comparisons can be made with other places in the Melbourne area.

An instrumented model airplane with radio control has been flown on several occasions with a view to locating the level of the temperature inversion which limits the upward diffusion of pollution on smoggy days. It also measures the intensity of ultra-violet light to give an indication of the decrease of aerosol pollution with height. It is not yet certain how useful this technique will turn out to be and more flights are planned.

Radioactivity, Dust and Surface Ozone

Airborne radioactivity is normally measured using a filtration technique, by which all atmospheric particles larger than about 0.2μ are removed. Weighing of the filters before and after exposure also permits the total particulate loading of the air to be measured to a high degree of accuracy. Since measurements were first made in 1966, the average solid content of the air at Aspendale has increased from less than 30 $\mu g\ m^{-3}$ to about 50. During the same period, a similar increase has occurred in the number of homes near the site, and it is possible that there is an association between the two.

Some attempts have been made to correlate the dust concentration in air with meteorological variables, in a similar manner to that employed for the concentrations of radon daughters near the surface. The two quantities, dust and radon, are found to give similarly negative results, in that concentrations of neither correlated well with wind speed or rainfall. Both show a large dependence on wind direction, with northerly winds giving the highest concentrations (Aspendale is south of the more heavily populated areas of Melbourne and is

close to the eastern shore of Port Phillip Bay). Also, both have a significant correlation with daily maximum temperature.

Ozone concentrations near the surface are found to behave in much the same way. A series of comparisons was made between ozone, dust and radon, and in all cases there were highly significant correlations between pairs. When partial correlations are calculated, it is found that dust and radon are highly correlated, as are radon and ozone, but not ozone and dust. It is therefore concluded that ozone concentrations are significantly influenced by those effects which determine radon concentrations - largely the rate of gaseous diffusion through the topmost layers of the soil surface. The negligible correlation found between dust and ozone is of interest since some workers have suggested destruction of ozone by particulates.

On a larger time scale a significant increase in surface ozone has been observed at Aspendale during the late summer and in the autumn. Since this cannot be wholly due to advection either horizontally or from above, it must be assumed to be generated locally. (Ozone is formed by the action of sunlight on nitrogen oxides and hydrocarbons, themselves products of petroleum combustion.) To determine the cause of the increase, correlations between surface ozone, ultra-violet radiation and ozone concentrations as measured by a sonde have been initiated.

As illustrated above, the Division is in effect conducting quite a varied programme of pollution studies at Aspendale. The philosophy is to aid in the development of more fundamental understanding of some of the processes of pollution and to contribute to methods of measuring it. Both developments should find application in more extensive pollution studies which local authorities may be expected to undertake through the years to come.

## VII RADIATION - ATMOSPHERIC AND TERRESTRIAL

### High Level Radiation Measurements

Experience with numerical weather forecasting techniques has shown that, when computing the fields of meteorological elements for a period of the order of several days, it is necessary to take account of sources and sinks of heat, not only at the earth's surface, but also throughout the depth of the atmosphere. An important role is therefore played by radiation processes, both in the range of solar (or "short wave") radiation, mainly 0.2 to 2 micrometres (μm) in wavelength, and in the "long wave" range of thermal radiation, 2-100 μm.

Clouds have a large influence on both radiation fields and much quantitative work remains to be done in this area. To this end increased attention is being given to the radiative behaviour of clouds.

A balloon-borne package of upward and downward looking radiometers which measure separately the short and long wave fluxes of atmospheric radiation has been developed. During the year it has been flown at Mildura in Victoria, and at Longreach in Queensland, as an addition to the normal HIBAL payload launched by the Department of Supply. These HIBAL balloons are normally launched just prior to dawn, and so radiation measurements have been obtained on the ascents covering the period of sunrise, and during the float period (at altitudes ranging from 21 to 32 km) with the sun at elevation angles between 4 and 45 degrees. The float data obtained from flights in clear skies have shown remarkable consistency from flight to flight, and place to place, and the various flights have allowed the construction of composite curves of the behaviour of the upper atmosphere radiation climate as a function of solar elevation.

Downward hemispherical colour photographs are taken continuously throughout the flights, and these have been analysed with a densitometer to give the intensity distribution of the short wave radiation emerging from the top of the atmosphere - again for

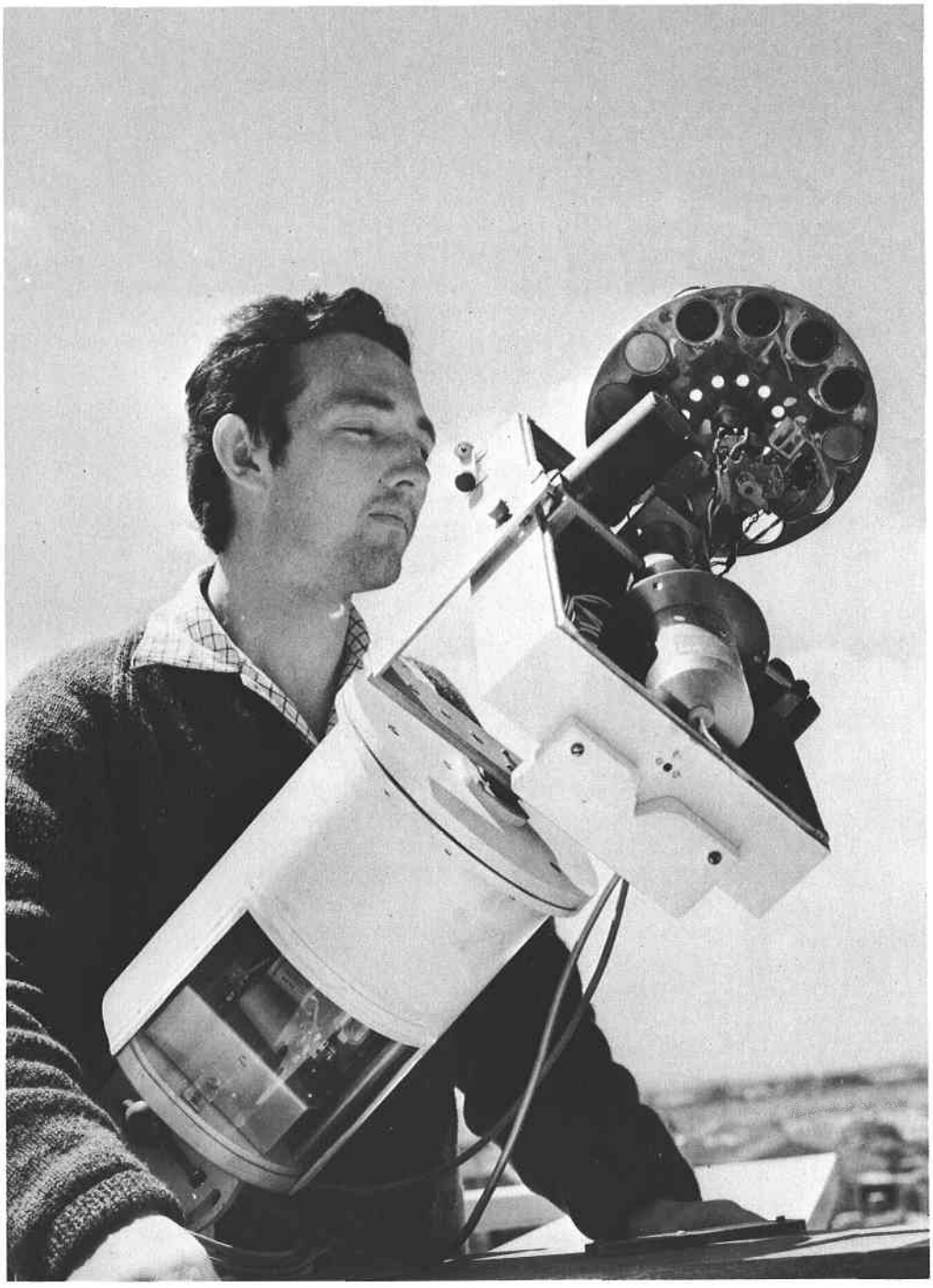
various solar elevations. These intensity distributions clearly show the effect of atmospheric dust scatter, but it is found that the effect of the dust on the total upward vertical flux of short wave radiation is negligible except when the sun is close to the horizon, when the dust increases the upward flux by about 1.5 per cent. Flights through and above various well defined cloud situations have yielded information on the short and long wave transmissivities and reflectivities of the clouds.

Clouds: Radiative Properties and Temperatures

Owing to strong absorption bands in the infra-red spectra of water vapour and carbon dioxide, the atmosphere is virtually opaque at most wavelengths beyond about 3 μm. An important exception is the 8 to 13 μm band, in the so-called "atmospheric window" - and it is this region which can be used to measure the emissivities of clouds. At high levels, where there is little water vapour, long wave radiation by the clouds to space is an important part of the overall atmospheric radiative balance. Many more detailed measurements are needed.

For this type of work a highly sensitive radiation thermometer has been developed in the Division for sensing the brightness temperature of small areas of the sky. It observes in the 10.5 - 11.5 μm band and has a beamwidth of only 1/3rd degree. It has now been fully operation for six months. The radiometer can also be used to sense remotely the radiative temperature of any terrestrial object to within $0.2^{o}C$.

In March a joint programme was carried out with the University of Adelaide Physics Department. Simultaneous measurements were made with the University's pulsed laser (Lidar) equipment and the radiation thermometer. The Lidar measured the height, thickness and backscatter from some cirrus and altocumulus decks, whilst the thermometer measured the cloud radiant intensity. During the course of the work some interesting results emerged, e.g. the particle density of a cirrus cloud deck changed by more than three orders of magnitude over



Lining up a spectral pyrheliometer

a period of several hours; and when the cirrus was barely visible to the eye, it could be clearly detected by the Lidar. An altocumulus deck, 700 m thick, had a transmissivity of about 50 per cent, whilst the intensity at the cloud base was far from isotropic.

Also found to be semi-transparent were some decoying storm anvils. In this case, measurements were made from Aspendale, using the Divisional 3 cm radar to provide heights and thicknesses of reflecting layers.

Instruments and Records

A hemispherically-detecting pyrgeometer which senses only in the atmospheric window is under development. It utilizes a magnesium oxide crystal as an absorbing plate, and will be used to measure radiation from clouds and clear skies.

Measurements of atmospheric turbidity by means of a pyrheliometer with suitable coloured filter glasses have been made at Aspendale on clear days over the past five years. These show the turbidity to have a maximum in spring and a minimum in autumn. The cause of this is being investigated.

An instrument to record the spectral distribution of direct solar radiation in eight broad bands has been completed: it is provided with a sun tracking mechanism and automatic filter holder rotation. This will give data useful for biological purposes, as well as for turbidity calculations. Daylight intensity on a horizontal surface can also be derived.

To the radiation quantities already recorded continuously at Aspendale have been added net long wave flux, downward long wave flux and screen temperature.

A digital current controller for the Ångström pyrheliometer has been developed which allows the balancing voltage to be selected in discrete steps by decade dials. The system is monitored by an inbuilt

1-volt transfer standard which has its own unsaturated reference cell. Overall accuracy is better than the maximum resolution of 0.04%. Variations in heater resistance of the Ångström have no detectable effect. The prototype has been followed by two comprehensive, self-powered portable units containing sensor, accessories, galvanometer, etc. These units have been constructed for the 1970 International Intercomparison of Radiation Standards at Davos, Switzerland, provision being made for simultaneous monitoring and use of external current sources when compatibility with a data-acquisition system is required.

Improving Radiation Standards

To improve further the accuracy of the W.M.O. Region V Radiation Standard maintained at Aspendale, one of the two Ångström pyrheliometers (No. 578) held by the Division was returned to Sweden where it was overhauled and recalibrated by the Swedish Meteorological and Hydrological Institute. After its return, a comparison with the primary instrument (No. 502) was carried out at Kerang in Northern Victoria during December. Good clear atmospheric conditions enabled a large number of measurements to be taken and the results showed the two instruments to agree within 0.2 per cent in terms of the Swedish calibrations.

The constant of No. 502 as given by the 1964 International Comparison of Davos is 1.3 per cent less than the SMHI constant. It is hoped that another International Comparison to be held at Davos in September, 1970, in which one of the Division's instruments will be included, will help to reduce the present uncertainty of around 1 per cent to perhaps 1/2 per cent or less.

In connection with a paper submitted to the 1970 International Solar Energy Society Conference, a short 16 mm colour sound film entitled "Radiometer Calibration" was produced by the Head Office Film Unit. This was well received at the conference.

## VIII AGRICULTURAL METEOROLOGY INCLUDING HYDROLOGY

The main interest of the Agricultural Meteorology group continues to lie with the exchange of water vapour and heat between earth and atmosphere. Apart from the importance of soil water loss by evaporation, including transpiration, in both agriculture and hydrology - especially in a water-short country such as Australia - the fluxes of heat and water vapour to and from the surface together, determine the effective environments in which plants and animals live, strongly influencing their rates of growth and even at times their survival. In the geophysical context, of course, the inputs of energy and water into the air from a variety of surfaces constitute one of the main regulating factors in the development of weather and climate on a macro scale.

### A Mathematical Plant Model

Only over the past few years has it become possible to incorporate the results of research on individual aspects of plant growth into overall simulation models. In general, it has been necessary to rely on empirical relations obtained from field experiments, and whilst the resultant models can be very useful they have their limitations. A major one arises from the uncertainty attaching to the physical or chemical basis of the empirical relations, and there is always the possibility that the model will apply only to the plant from which it was obtained.

Over the last two years, an attempt has been made to model a pasture or crop in a somewhat different manner. Although the model is designed to simulate a real pasture as far as possible, this is always subject to the conditions that the model must never incorporate empirical relations of plant growth which we do not understand. The main advantage of such an approach is that the resultant model, while not necessarily real in all aspects, is self-consistent. It can be used as an ideas generator for suggesting future field experiments, and as a means of explaining why a plant, growing in a

particular environment, evolves the way it does. It is rather surprising (and gratifying) that the model, with all its simplifications, appears as if it might be quite reasonable as a pure simulator of an actual crop - although it has yet to be tested experimentally in the field.

A major effort this year has been directed to designing a more suitable root and soil system which can be matched to the above ground canopy. Preliminary work on the subject has shown up the interesting possibility that (in the evolutionary sense) it may be advantageous for plants to put down roots in compact "bunches" - rather than spread them evenly throughout the soil. In this way, the total water use of a crop may be restricted and be used more beneficially by the plant than if it simply restricted its total root length.

Evaporation - Instrumentation and Estimation

The lack of a suitable water vapour sensor has long been a stumbling block holding up the measurement of evaporation by the Fluxatron. This instrument measures atmospheric fluxes via the eddy correlation technique and incorporates long time constant filters (80 secs) to remove the mean level of the fluctuating quantities as well as the long period eddies which contribute nothing to the flux. Recently, however, a device developed by Gjessing to measure relative humidity has been tried out as a possible solution. The principle is absorption of water vapour by a coating of hygroscopic material on an oscillating quartz crystal.

During a field experiment a series of measurements were made of net radiation (R), ground heat transfer(G), sensible heat flux (H), and evaporation (E). For a correct energy balance (and by inference on accurate determination of the quantities involved), (E+H)/(R-G) should equal unity. This relation was satisfied with an accuracy of 4%.

In contrast to the earlier fine-wire wet bulbs which require both extreme cleanliness and a carefully adjusted water feed for satisfactory

operation, the Gjessing hygrometer proved to be very easy to use in the field. Since relative humidity is the quantity measured, an independent measurement of H is required before E can be evaluated - as is the case if a wet bulb is employed.

The most reliable way of measuring daily crop evaporation is by means of weighed lysimeters, and the Division's main stay in this context continues to be a battery of 10 large (6-ton) lysimeters, automatically and continuously weighed to the equivalent of 0.025 mm of surface water.

Such systems are expensive and there is a need for a simple, rugged and reliable field unit accurate to about 0.25 mm of water. The hydraulic-pneumatic system already developed and patented is currently undergoing simplification in design and is ultimately intended for use as a basis of a lysimeter network by another agency. With low cost in mind, another type of lysimeter balance is in the developmental stage. It employs thin steel cables as pivots and is designed for assembly in the field, simultaneously with the installation of a monolith lysimeter.

A portable instrument known as the Energy Partition Evaporation Recorder (EPER) has been further developed during the year. It measures evaporation by means of an analogue circuit which continuously solves a modified version of the Bowen-ratio formula, using measured values of net radiation, ambient wet bulb temperature, and dry and wet bulb temperature differences. Field trials conducted at various sites around Melbourne have shown the present version of the instrument to compare favourably with high grade lysimeters and to be particularly well suited to short-term investigations. Recent work has been directed towards improved accuracy in sensing the main variables, and reduced construction costs.

In many places where at least an idea of the evaporation rate from a land surface is needed, resort can often be had to indirect means employing estimation formulae. One such approach, known as the Combination Method, utilises standard

measurements of net radiation, wind speed, temperature and humidity. It takes into account the energy available at the surface, the diffusion of heat and water vapour through the air immediately above the crop (via an atmospheric conductance, h) and the diffusion of liquid and vapour through the soil and plant (via an internal conductance, $h_i$).

Over the past few years, work on pasture, potatoes and barley has established h as a simple function of wind speed. Recently, $h_i$ has also been related to soil moisture content, as well as to various indices of plant moisture status, and a more precise quantitative link is now being sought. Results to date have been very encouraging and promise a means of deriving actual evaporation from potential evaporation, the latter estimated from meteorological data alone or even from empirical pan relationships.

A knowledge of the mass and energy balance of snowfields and in particular their evaporation and melt rates is important in management of water resources and in atmospheric circulation studies. The large snow-lysimeter balance built at the Division, for direct measurement of evaporation and melt rate from snowfields, was tested at Fall's Creek, Victoria, during Spring 1969. In order to test a modified combination method formula for estimation of snow evaporation, instruments for the measurement of net radiation, windspeed, temperature and humidity were also installed and tested. Poor snowfall in the area, however, precluded a full-scale programme of measurements being made. The instruments, with some minor modifications, have been re-installed during Autumn 1970 in readiness for a further measuring programme in the coming Spring.

The standard neutron soil moisture meter is not very suitable for field observations in dense crops. To improve the situation, the sensing head and pre-amplifier have been redesigned so that a single lightweight lead, up to 100 m long, may be used between it and the rate-meter. This system has increased speed and reliability, since an

adequate number of calibration holes can be included in the extended test pattern.

## The Growth of Tobacco Plants

At the request of the Tobacco Research Institute in Mareeba, North Queensland, the Division is co-operating in a project to measure the fluxes of u.v. and photosynthetically-active radiation both in and above tobacco crop canopies. This experiment is aimed at understanding the meteorological factors which control the production of "lug" tobacco leaf, which normally appears very low on the plant and which is at a premium on world tobacco markets.

It is suspected that the amount of lug leaf per plant is related to the quality and quantity of radiation close to the ground. Equipment based on silicone solar cells and diffusing glass optical filters (to remove non-photosynthetically-active radiation at wavelengths greater than 0.8μ) has been built. Both the solar cells and the filters are relatively cheap and can therefore be used in large numbers to give adequate replication. The instruments are now operating in the field at Mareeba, each level in the canopy being sampled by upwards of 30 filter cell combinations, the outputs from which are fed, in series, to integrating watt-hour meters. It is hoped to establish whether the change in radiation climate at the lower levels of the plants (from summer to winter) is the reason for the better yield of lug leaf in a winter crop. Simple equipment to measure the u.v. component of in-crop radiation (based on optical glass filters and photoelectric cells) has also been built and is operational.

## Evaporation and Drag Coefficients in a Vineyard

At the invitation of the Research School of Biological Sciences, A.N.U., officers of the Division participated in field work in a vineyard at Griffith, N.S.W. The experiment called for measurements of the sensible heat flux and the Reynolds stress using Fluxatrons at a height of 4 metres. This offer provided an excellent

opportunity to find out how the drag coefficient varied with inclination of the wind to the rows of vines - in contrast to earlier work which has always involved homogeneous surfaces.

The results were as follows: When the crop was young and the wind blew parallel to the rows, the drag coefficient equalled 0.008, but with the wind at right angles to the rows, the drag coefficient increased to 0.025. No comparable variation was found in the case of sensible heat transfer. When the crop was more mature, there was a similar variation of drag coefficient with wind direction (relative to the rows) except that both figures were higher.

Evaporation losses for the vineyard were estimated from an energy balance, using actual measurements of net radiation, ground flux and sensible heat flux. In this case, an increased water loss was observed when the wind blew across the rows. This result needs further substantiation, but raises the interesting possibility that the orientation of the rows with respect to the prevailing wind direction may be a significant factor in crop performance.

River Flow Measurement

The measurement of river discharge continues to be of major importance in many aspects of the development of water resources. This is especially so in Australia, where access to rivers is often a problem, distances large, and where in the more arid regions of the country 80% of the total run-off may occur during floods of relatively short duration.

A report of the River Flow Committee of the Australian Water Resources Council recommended that an evaluation be made of the rising float technique for the measurement of river flow. In this method a float is released from the bed of the river and the distance downstream of its point of emergence used to provide a measure of the discharge. The Division undertook a small pilot study and after some preliminary investigation a mechanism was

constructed which enabled plastic balls to be released under water. The balls had a diameter of 5 cm and were partially filled with water to provide two different effective densities.

Initially, the balls were released from the bottom of a swimming pool and their behaviour observed, as it is important in this context that they attain their terminal vertical velocity as quickly as possible. In fact, in the first 1 - 2 ft there is some deviation from the simple behaviour, but for rivers of sufficient depth (i.e. greater than 10 ft) this has no practical significance.

A comparison with the standard current meter technique was carried out for three rivers: the Yarra at Yering, with a discharge of 250 cusecs; the Goulbourn at Seymour (3,500 cusecs); and the Murray at Murrabit (10,500 cusecs). For the larger rivers, the difference between the two methods was less than a few per cent. The double rising float technique, which does away with the need to know the point of release, could be used for the larger rivers with an accuracy of better than 10 per cent.

Having completed the initial pilot study, the Division does not plan to expand its activities in this area.

General

The hydrological significance of plant water stress and of plant control of evaporation under apparently plentiful water supply has been widely debated in the literature. The Aspendale investigations have demonstrated that evaporation control by potatoes and the non-grass components of pasture amounted to one fifth of the potential evaporation on some 10% of summer days. There were accompanying measurable, but not always visible, symptoms of plant moisture stress. Less severe restriction and stress - but perhaps sufficient to depress growth - occurred on many other days. Such effects may well be significant in short term (daily or weekly) water use, if not on a seasonal or annual basis.

A second comprehensive field investigation into the micro-climate, water use and growth rate of a barley crop was carried out jointly with several departments of Melbourne University at the School of Agriculture's Research Farm at Mt. Derrimut. A large quantity of data was obtained and analysis is under way.

## IX COMMONWEALTH METEOROLOGY RESEARCH CENTRE

In collaboration with the Bureau of Meteorology, the Division now operates the Commonwealth Meteorology Research Centre. The work of the Centre has two principal objectives; a better understanding of the fundamental process of meteorology, in particular the large-scale behaviour of the earth's atmosphere, and the application of this knowledge towards improvements in the accuracy and time-scale of predicting the atmosphere's behaviour. In the first year of its existence the Centre's activities have been directed strongly towards the second of these objectives, in that emphasis has been placed on work designed to aid the Bureau of Meteorology's operational activities in the fields of weather analysis and prognosis. However, it is expected that in course of time the full scope of activities envisaged for the Centre will be developed.

The running of the Centre is overseen by a committee comprising the Chief of the Division, the Director of Meteorology, and the Officer-in-Charge of the Centre (Dr. G. B. Tucker). The Centre's achievements to date are described in an independent Annual Report, in format broadly similar to this one.

## X MISCELLANEOUS

### Forest Fires

Every year great damage is done to Australian forests and grasslands by wild fires, often so intense as to be completely uncontrollable. At this stage there is a need to build up a body of meteorological knowledge on how a fire is likely to

behave in a given set of circumstances so that, when necessary, steps can be taken to move people and stock to safety.

In collaboration with the Division of Applied Chemistry, two expeditions have been undertaken to obtain measurements around and above forest fires. In the first of these, reported earlier, use was made of five of the fires regularly lit by the W.A. Forests Department to clean up the litter on the forest floor to protect the forests against the intense wild fires. Though of considerable area (typically 40 - 50 $km^2$), these fires are lit under conditions which experience has shown will keep them relatively mild. Using an aeroplane, information was obtained on the turbulence in the smoke plumes and on the temperature structure around and above the fire. Good agreement was found between the amount of heat carried away by the wind and the foresters' estimates of quantity and calorific value of the fuel.

In December, 1969, the opportunity arose of studying three much more intense fires, also in Western Australia. Although the fuel quantities were not very much greater than in the earlier cases, the fires were lit under drier conditions and in the absence of the inhibiting effects of a strong inversion. As a result, the smoke plumes rose to heights of 3,000 m in two cases and nearly 4,500 m in the other. In the two milder fires the heat supplied from the fuel could be reconciled with that stored in the smoke plume by assuming an entrainment factor of about 2. In the most intense fire, the air above condensation level was conditionally unstable and a very much greater degree of dilution by the ambient air is necessary to explain the relatively restricted heights reached by the plumes. Turbulence measurements similar to those of the previous observations were also made. Generally speaking, extreme turbulence was confined to the central core of the plume immediately above the fire. On one occasion in this region the sounding aircraft rose 400 m in 30 sec - the controls being held for level flight.

## General

The Division has continued its work as an accredited laboratory of the National Association of Testing Authorities in the fields of low speed anemometry and atmospheric radiation instruments. In the case of the former, the number of instruments calibrated has increased by nearly 50 per cent over last year to a total of 180: most of these were for commercial fiems, but some were for Commonwealth and State Government Departments. The number of radiometers calibrated has also shown a progressive increase and now stands at 230 per annum.

In response to an invitation issued through the President of the World Meteorological Organization Region V, the national radiation standard for Malaysia (an actinograph) was received for calibration and also a solarimeter from the Philippine Islands.

The computation and data processing group has continued to assist with research projects of the various groups of the Division. The analogue-digital conversion system, which was partly completed last year, has now been put into service and has greatly facilitated the processing of high frequency meteorological data. The system accepts data in a variety of forms and produces computer compatible digital magnetic tapes. A start has now been made on the construction of the typewriter and a paper tape reader, mentioned in last year's Annual Report.

## Instrument Development

Electronic sensing heads consisting of crystal thermometers with a resolution of 0.001°C are the basis of a new field temperature-gradient facility. New housings and aspirators were developed and tested so that full use could be made of the improved characteristics for differential and absolute measurements. The latter are printed out, producing simultaneously a computer-compatible punched paper tape complete with channel identification. Direct comparison can be made at

any time between the two records by reading the coded punching.

Radio-controlled model aircraft can be used to take sensors to heights beyond those attainable using masts, and the Division is helping to develop this technique on behalf of many other potential users. However, telemetry can sometimes cause interference with the sensitive airborne receivers used for aircraft control. To overcome this, data may be stored on a miniature tape recorder located in the aircraft, and for this purpose miniature current-to-frequency converters have been developed. On the ground the replayed output can be readily reconstructed into an analogue of the original signal for processing.

An automatic battery-powered anemometer unit has been devised, having four channels and able to count and print out the individual total runs of wind at various intervals. Provision is made for extending the number of channels and increasing the choice of time intervals. Manual control for resetting, printing and synchronising is available for spot checks and setting-up.

## XI ACTIVITIES AND PERSONALIA

It is with great regret that we have to record the death of Mr. C.J. Sumner. Mr. Sumner, an Experimental Officer, had been with the Division for 17 years. He was responsible for the development of the long-term recorder which carries his name, and many other instrumental developments and innovations.

Members of the Division have maintained their contact with other 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.

In October, 1969, Dr. C.H.B. Priestley attended the Third Session of the Joint GARP Organizing

Committee held in Paris. En route, he visited meteorological centres in the U.K. and the U.S.A.

Mr. W.C. Swinbank was recently elected a Fellow of the Australian Academy of Science. Currently he is away from the Division on two years' leave of absence and is with the National Center for Atmospheric Research, Boulder, U.S.A.

Attached to the United Arab Republic Meteorological Research and Training Institute, Mr. I.C. McIlroy recently completed three months in Cairo as a W.M.O. adviser.

At the invitation of the U.S.S.R. Academy of Sciences, Dr. A.J. Dyer and Mr. B.B. Hicks left for Moscow in June, 1970, to take part in an International Comparison of Instruments measuring atmospheric turbulence, taking the opportunity en route to visit meteorological establishments in Japan and India. Mr. Hicks will continue to the U.S.A. to commence a nine-months' attachment to the Argonne National Laboratory where he will be working on radioactive atmospheric tracers.

Dr. D.E. Angus, who has been with the Division since 1950, resigned in January, 1970, to take up an appointment as Reader in Botany at the University of Queensland.

At the end of the period under review, Mr. V. Sitaraman, a Colombo Plan student from the Bhabha Atomic Research Centre, India, completed a twelve-months' attachment to the Division. His work was in the field of atmospheric diffusion and the evaluation of potential health hazards arising from the discharge of radioactive effluents at reactor sites.

In May, Dr. T. Schneider, who had been with Division on a two-year Fellowship, working on the measurement of carbon dioxide in plant communities, returned to Wageningen.

## XII PUBLICATIONS

BERSON, F.A. (1969) Fallout from storm anvils. Aust. Met. Mag., 17 (3) : 113-133.

BLEVIN, W.R., B.G. COLLINS and W.J. BROWN (1969) A comparison of two radiometric scales. Pure and Appl. Geophys. (PAGEOPH), 77 (VI):189-192.

CLARKE, R.H. (1970) Observational studies in the atmospheric boundary layer. Q. J. Roy. Met. Soc., 96 (407) : 91-114.

CLARKE, R.H. (1970) Microbarograph observation of acoustic gravity waves. Nature, 225 : 535.

DEACON, E.L. (1969) Physical processes near the surface of the Earth. World Survey of Climatology (Editor-in-Chief: H.E. Landsberg) Vol. 2 General Climatology (Editor: H. Flohn), Chap. 2 : 39-104. Elsevier Publishing Co.

DEACON, E.L. (1970) The derivation of Swinbank's long-wave radiation formula. Q. J. Roy. Met. Soc., 96 (408) : 313-319.

DYER, A.J., B.B. HICKS and V. SITARAMAN (1970) Minimizing the levelling error in Reynolds stress measurement by filtering. J. Appl. Met., 9 (3) : 532-534.

GALBALLY, I. (1969) An evaluation of the Ehmert technique for measuring ozone profiles in the atmospheric surface layer. J. Geophys. Res., 74 (28) : 6869-6872.

HICKS, B.B. (1969) A simple instrument for the measurement of Reynolds stress by eddy correlation. J. Appl. Met., 8 (5) : 825-827.

HICKS, B.B. (1969) Sulphur-35 and Beryllium-7 in ground level air at Aspendale. Nature, 224 (5215) : 172.

HICKS, B.B. (1970) The measurement of atmospheric fluxes near the surface: A generalized approach. J. Appl. Met., 9 (3) : 386-388.

HILL, R.H. (1969) A d.c. millivolt integrator. J. Sci. Instrum. (J. of Phys. E), Series 2, 2 : 616-618.

HUNT, B.G. (1969) Experiments with a stratospheric general circulation model. III Large-scale diffusion of ozone including photochemistry. Monthly Weather Review, 97 (4) : 287-306.

HYSON, P. (1969) Physics of measurement of the wire temperature sensing system for rocket systems. In "Stratospheric Circulation", Progress in Astronautics & Aeronautics, 22 : 167-174.

McEWAN, A.D. (1970) Inertial oscillations in a rotating fluid cylinder. J. Fluid Mech., 40, Pt. 3 : 603-640.

PALTRIDGE, G.W. (1969) A note on the calculation of aerosol absorption from solar radiation measurements. Q. J. Roy. Met. Soc., 95 (405) : 650-652.

PALTRIDGE, G.W. (1969) A net long-wave radiometer. Q. J. Roy. Met. Soc., 95 (405) : 635-638.

PALTRIDGE, G.W. (1970) Reflection from elevated layers in the troposphere. Proceedings IEE, 117 (1) : 23-26.

PALTRIDGE, G.W. (1970) A filter for absorbing photosynthetically-active radiation and examples of its use. Agric. Meteorol., 7 (2) : 167-174.

PALTRIDGE, G.W. (1970) A model of a growing pasture. Agric. Meteorol., 7 (2) : 93-130.

PITTOCK, A.B. (1970) On the representativeness of mean ozone distributions. Q. J. Roy. Met. Soc., 96 (407) : 32-39.

PITTOCK, A.B. (1970) Ozone behaviour associated with the middle stratospheric circulation during the Southern Spring of 1967. Q. J. Roy. Met. Soc., 96 (408) : 214-225.

PRIESTLEY, C.H.B. (1970) Interaction between oceans and atmosphere. Proc. Symposium on Marine Sciences, Canberra, May 1970. Reports of the Aust. Acad. Sci. No. 12 : 25-42.

SHEPHERD, W., and A.C. DILLEY (1970) Some aspects of evapotranspiration and moisture stress of pastures. Proc. of the XI Internat. Grassland Congress, Australia 1970, Sect. V : 496-498.

SCHNEIDER, T. (1969) The block-method for measuring flux density at the surface of soils and other solids. Agric. Meteorol., 6 : 423-434.

SCHNEIDER, T. (1969) A thermocouple psychrometer and its use for the measurement of water vapour pressure near the Earth's surface. Archiv für Met., Geophys. und Bioklim., 17 (Series B) (4) : 391-402.

SUMNER, C.J., and G. PATTERSON (1969) A sun-tracking radiation instrument stand. Solar Energy, 12 (4) : 537-542.

SWINBANK, W.C. (1970) Structure of wind and the shearing stress in the planetary boundary layer. Archiv für Met., Geophys. und Bioklim., 19 (Series A) (1) : 1-12.

WEBB, E.K. (1969) The temperature structure of the lower atmosphere. Proceedings of REF-EDM Conf., Univ. of N.S.W., Sydney, Nov. 1968. Refraction Effects in Geodesy, Paper No. 1 : 9 pp.

WEBB, E.K. (1970) Profile relationships: The log-linear range, and extension to strong stability. Q. J. Roy. Met. Soc., 96 (407) : 67-90.

# XIII STAFF

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