Commonwealth Scientific and Industrial Research Organization

DIVISION OF
METEOROLOGICAL PHYSICS

ANNUAL REPORT 1968-69

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Division of Meteorological Physics

Commonwealth Scientific and Industrial

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I INTRODUCTION

The Division has two principal objectives: a better understanding of the fundamental processes of meteorology and the application of this knowledge to problems of economic importance to Australia. In the case of the former, there is for example the group working in large scale atmospheric dynamics, and in the latter, studies of a more practical nature, such as the effect of reeds on the evaporation from a lake. More directly related to immediate needs is the work in agriculture and the efficient use of water by plants. It is in such spheres 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) Numerical modelling of the Atmosphere. Further evaluation of the 14-day Southern Hemisphere prediction tests carried out in collaboration with the American Geophysical Fluid Dynamics Laboratory shows that the rainfall predictions, although quantitatively leaving room for improvement, exhibit some skill for a forecast of up to at least three days. Correlation between normalized predicted and observed rainfall over Australia was .65 on the first day of forecast.

(b) The Boundary Layer. Data from the Wangara expedition of 1967, still in process of evaluation, are being used to check the similarity theory of turbulent transports in the boundary layer.

The universal profiles deduced from theory have been calculated for temperature, humidity and

wind, whilst those of the eddy transfer coefficients for heat, moisture and momentum are in the process of being computed.

Under fairly steady day-time conditions, the scheme derived from dimensional analysis yields reasonably consistent results, but under other, not uncommon, conditions deviations from theory can be large.

Thus, simple application of the similarity scheme provides a first approximation to the problem of modelling the boundary layer for numerical simulation experiments, but the models must be formulated which are able to take time and space variability of the boundary layer into account.

(c) Mechanisms responsible for the Vertical Interchange of Heat, Water Vapour, Momentum and the Production of Kinetic Energy in and above the Boundary Layer. Scales of motion producing these interchanges are known to vary greatly with distance from the earth's surface, where only small scale motions are involved. Preliminary results from the Wangara expedition indicate that at heights of about a kilometre, motions on the scale of 80 km up to the size of weather-map disturbances are important for the interchange of heat and water vapour.

Large downward eddy fluxes of momentum have been observed in the vicinity of meridional cold fronts, but the indication is that in totality this scale of disturbance makes only a minor contribution to the vertical transfer of momentum on a global scale.

(d) Variability of Meteorological Elements over a Flat Continental Region. Experimental results from 40 days' continuous observations at Hay during winter time have made possible analysis of the scale of variability of many elements, including mean vertical air velocity (averaged over an 80 x 80 km square). This indicates rather pronounced diurnal components in all variables. The midnight wind maximum, at and above 50 m, linked with the low level jet mechanism, is well marked, as is the inertial period of about 21 hours, while the

vertical velocity evinces a midday maximum of about .5 cm per sec at 1 km — a result of differential heating on a continental scale.

The theoretically expected turning of the wind with height in the boundary layer nearly vanishes in the average during the warmer part of the day, confirming the earlier observations made in summertime.

(e) Equatorial Pressure and Wind Variations. A study is being made of the time and space scales of equatorial pressure variations. Preliminary examination shows that a considerable amount of the variance is found at low frequencies, e.g. spectrum analysis of five years of daily pressures at Djakarta shows a peak in the vicinity of six weeks.

There is a possibility that some of the pressure fluctuations are associated with stratospheric divergence. Some twelve-day variations examined showed a tendency for eastward propagation, and it could be speculated that this is in response to the behaviour of the recently reported Kelvin waves in the equatorial stratosphere, which have about the same period and also propagate eastward. From observations made in the equatorial stratosphere during atomic tests, fluctuations of 10 - 15 days period in the zonal component were found, though their average amplitude — about 3 - 5 m/sec — was considerably less than the 5 - 8 m/sec reported previously in the literature.

(f) Oscillations in the Stratosphere. Long term variations of wind, temperature and heat transport in the stratosphere were further examined for quasi-periodic cycles and for modulating effects by the sun-spot cycle. For this purpose orthogonal band-pass filters with the required response functions were developed and tested on random and long meteorological time series. For example, an 80-year record of mean sea-level pressure at Darwin shows no statistically significant response with any of the filters used (periods from 6 months to 24 years), excepting of

course the annual oscillation. However, during the six years 1954 to 1959, which are centred on the largest sun-spot number observed since reliable records began, a transient response in the semi-annual and biennial frequency bands was recorded simultaneously with a sharp reduction in the amplitude of the annual oscillation. These "signals" in the sea level pressure in the tropics during extreme sun-spot activity indicate that the well documented quasi-biennial stratospheric oscillation in the 1955-63 epoch is dynamically coupled with the semi-annual oscillation, supporting our earlier hypothesis of sub-harmonic response to semi-annual forcing.

Radar Meteorology

(a) Dry Cold Fronts. Analysis of the three-year observations on the structure of band echoes from the vicinity of dry, cold fronts referred to last year, has been resumed following a conclusion reached as a result of a joint investigation with the Victorian Ornothologists Research Group.

It had been thought that the echoes — which occur in conjunction with sea breezes and summer cold fronts moving in-shore from Port Phillip Bay — might be attributed to the transient migration of birds, since the conditions favouring spontaneous congregation are the very ones required to produce the echoes, viz. marked frontal wind shear, convergence and up-draft. However, all the evidence points to there being little or no connection between the two phenomena.

(b) Ice Crystal Fallout. Further observations were made of echoes originating in the upper troposphere downwind of rainclouds. In one instance mentioned earlier, the phenomenon was attributed to ice crystal fallout from a cirrus cloud canopy associated with, but remote from, a tropical depression. The same type of echo has since been observed on the Aspendale radar, ahead of frontal and convective precipitation. More conclusive evidence of "crystal precipitation" was subsequently obtained during an intensive radar study

of thunderstorms in S.E. Queensland. Using the radar facilities of the Bureau of Meteorology at Brisbane, measurements were made of the reflectivity of storm cells and downstream layer echoes which come from below the level of anvil cloud. The measured reflectivity range in the layers is consistent with ice crystal measurements (made at the same height) by the C.S.I.R.O. Division of Radiophysics and other workers overseas.

The extent and frequency of crystal fallout emphasize its potential for natural ice seeding of middle-level and growing storm clouds, and thereby for the propagation and organization of storm cells into systems leading to widespread rain. Further work is planned to investigate the implications of fallout for the seeding process.

(c) Radar Rain Echoes — Correlation with Wind Speed. Analysis is proceeding of observations on the behaviour of a large number of radar rain echoes. These are being correlated with wind, temperature and humidity with a view to describing in detail a typical convective shower in the Melbourne area. Echo movements correlate best with the mean wind averaged over the layer 1.2 to 3.6 km, although correlations with wind at 2.4 km are still very high. Wind relative to the echo at this level averages about 0.5 m/sec from the left, and 1 m/sec from the front.

III THE UPPER ATMOSPHERE

Ozone

Observations of total ozone and determinations of its vertical distribution by the Umkehr method have continued at Darwin, Brisbane, Aspendale, Hobart and Macquarie Island. A new station has been established in Perth and regular ozone observations begun in March 1969. This work is carried out in collaboration with the Bureau of Meteorology and the Antarctic Division of the Department of Supply. The regular weekly ozone soundings using the Brewer-Mast ozone sondes have continued at Aspendale, and also the daily observations of surface ozone at Aspendale and

Macquarie Island using Ehmert's type of instrument. Two surface ozone instruments have been sent to Mawson with the ANARE expedition to measure ozone fluxes into the Antarctic snow surface.

As reported earlier the enhanced radiation on B wavelength was attributed to the emission from the Herzberg band of molecular oxygen and to OH emissions. Since then a triangulation method has been employed to determine the height of the emission layer. Using the moon as a source, simultaneous measurements were made on Dobson Spectrophotometers at Renmark in South Australia and Griffith in New South Wales (separated by 500 km) and the computed altitude found to be 86 ± 7 km. The diurnal variation of the emission intensity was also determined and from these facts has emerged fresh insight into the dynamics of the upper atmosphere. On the basis of the photochemical excitation theory, assuming adiabatic oscillations, vertical transport velocities and eddy diffusion coefficients were calculated at these heights.

Vertical velocities at two levels, 100/50 mb and 30/10 mb, have been computed on a daily basis and averaged over a month for various localities in Australia. The descending motion at Darwin in winter and spring, when total ozone amount is much higher than in the corresponding season in the Northern Hemisphere (where there is ascending motion), is consistent with a relatively small seasonal variation of ozone in the equatorial regions of the Southern Hemisphere. From such vertical velocities, together with others inferred from radiation measurements made over Antarctica, it is intended to describe circulation processes at heights above 100 mb.

Ozone behaviour associated with the passage of cold troughs and warm ridges in the middle stratosphere over Aspendale, Hobart and Macquarie Island during the spring of 1967 has been studied in some detail. At this time, the Antarctic polar vortex was markedly elongated. At Macquarie Island ozone and temperature figures indicate a descent rate of air to the rear of the trough of about 1 cm/sec with negligible changes of temperature but

significant ones of ozone, resulting from horizontal advection.

Analysis of the data obtained from the 1966 synoptic network of ozone soundings strikingly confirms the transfer of ozone rich stratospheric air into the troposphere from the poleward side of the jet stream in the vicinity of the 300 mb troughline. A result of earlier work, a similar "folding in" process in the vicinity of the jet stream, was described in last year's report.

The study of ozone distribution according to a synoptic classification scheme has shown highly significant differences between mean ozone distribution in ridges and troughs and that obtaining on either side of the middle latitude jet stream. It is hoped to elucidate the reasons for this as more data becomes available.

A comparison of mean ozone distributions as determined by ozone sonde and Umkehr techniques has revealed that the selectivity arising from the fact that the Umkehr method can only be employed under certain weather conditions, leads to a systematic under-estimation of the mean ozone content in the lower stratosphere by as much as 10 to 35 per cent of the annual mean content.

Recent measurements of surface ozone at Aspendale, some 20 miles south-east of Melbourne, have revealed that ground level concentrations are sometimes more than twice the maximum values so far observed in the high troposphere, the greatest, so far, being 0.11 parts per million by volume. This has been explained in terms of local ozone production near the earth's surface by the action of sunlight on air pollutants such as oxides of nitrogen and hydrocarbons.

Measurements of ozone profiles near the earth's surface, and thus of ozone fluxes, have made it possible to evaluate ozone destruction rates at ground level. A typical figure of the flux into a dry grass surface during daytime in conditions of good mixing is about 3.7×10^{11} mol. cm^{-2} sec^{-1}. The ozone flux is

found to be dependent on the local ozone concentrations. This work was carried out in an area remote from urban pollution.

Radio Activity and Volcanic Dust as Atmospheric Tracers

The routine measurements of Beta-activity of rainfall have continued, though airborne tracers are now receiving a greater emphasis. During the past year, the techniques of measuring the cosmic-ray produced radio isotope Beryllium-7 (Be_7) in air, have been improved and this programme now operates routinely. An extensive body of data has been built up.

It is proposed to extend the Be_7 programme by establishing a network of stations at Townsville, Brisbane, Sydney and Hobart. As well as seasonal and latitudinal variations, tropospheric-stratospheric interchange will also be studied.

The mechanism responsible for the production of Be_7 in the stratosphere is still imperfectly understood: to improve our knowledge of the process, Be_7 measurements are now being made at two latitudes. Using equipment kindly loaned by the U.S. Atomic Energy Commission, and through the good offices of the Department of Supply who operate the Hibal facility, observations are obtained four times a year from Mildura, Victoria, and twice a year from Longreach, Queensland.

As further confirmation that our understanding of the cosmic-ray production model for natural radio activity is correct, Sulphur-35 measurements at Aspendale were compared with the predictions from theory. No significant differences were detected.

Following the successful study of volcanic dust in the stratosphere after the eruption of Mt. Agung at Bali in 1963, via radiation observations, much of the recent effort in this context has concentrated on increasing our understanding of the observed post-Bali behaviour.

The current opinion regarding the poleward transport of stratospheric tracers is strongly in favour of anisotropic eddy diffusion with mixing taking place polewards and downwards. (A number of recent studies overseas have suggested values for the anisotropic diffusion coefficients K_{yy}, K_{yz} and K_{zz}.)

The Bali dust data reported total amount in a vertical column and suggested poleward moving waves of dust in late winter, the wave amplitude being constant with latitude. This information can be used to infer values for the anisotropic diffusion coefficients, K_{yy} and K_{yz}, as functions of latitude. The K_{yy} values are in reasonable agreement with those reported elsewhere, showing a maximum of about 1.5×10^{10} cm^2 sec^{-1} in middle latitudes. The K_{yz} values are less satisfactory, and are higher than reported elsewhere. This may be connected with the possibility of a constant wave amplitude being partially due to the creation, in situ, of particles from sulphurous gas emitted by the volcano.

IV GENERAL MICROMETEOROLOGY

An investigation of mean profiles in the lower atmosphere has been extended as far into the stable regime (nighttime conditions over land) as is possible from available data. It is found that the "log-linear" law remains valid over a surprisingly wide range of stability, the same representation being valid for wind, temperature, and humidity. The value of the Monin-Obukhov coefficient α is found to be approximately 5. The Richardson number (Ri) has a critical value, representing the limit of the turbulent regime, equal to $1/\alpha$, i.e. approximately 0.2. However, a different regime intervenes at about Ri = 0.16 and extends through to values of Ri approaching 1; in this range the profiles are only quasi-determinate, approximating, on average, to a simple logarithmic form.

This knowledge of the profile forms in stable conditions has immediate application in the evaluation of fluxes from gradient measurements, and

has been so applied in the Wangara investigation. It also has potential application to some problems of nocturnal cooling, frosts, and atmospheric pollution.

Reference has been made in earlier reports to the cool skin (about 1 mm thick) of open water surfaces; in weak to moderate winds, the true surface temperature of the water can be up to 0.5 deg C or more cooler than that of the bulk water. An elementary theory of this layer, based on the instability associated with the gradients of temperature in fresh water, together with salinity in the case of salt water, is now being extended to include the effect of surface tension variations. While final results are not yet available, it appears that the surface tension effect brings about a significant reduction of the theoretical thickness of the layer and temperature drop across it.

To extend the observational knowledge of the skin layer, which is at present very meagre, it is proposed to make a fairly extensive series of measurements of the skin temperature drop. Equipment has been built, for operation at the end of a pier, to make sensitive measurements of the mean temperature and humidity structure in the air layers up to a few metres above the sea. From these, it is possible by extrapolation to determine the temperature right at the water surface, which can then be compared with that of the bulk water as measured just below the surface.

Knowledge of the cool skin will have application in improving current methods of evaluating the evaporation from lakes or the sea, and will also be relevant in the determination of sea temperature by measurement of radiation from above, e.g. from aircraft or satellite.

As a result of an investigation, reported previously, on the spectrum of the vertical velocity component of turbulence as measured from an aircraft, it became possible to evaluate the "scale length", of the turbulence (the value of which is of considerable interest, in particular, to aeronautical engineers) at a number of heights and

in various stability conditions. Two independent estimates of scale length obtained from the spectrum showed satisfactory agreement with each other. The scale length has been shown to increase with increasing height (at least up to 300 m) and with increasing instability.

The same spectrum analysis also makes it possible to calculate the rate of viscous dissipation of kinetic energy at various heights. The analysis is not yet complete but preliminary results indicate good agreement with previously published estimates close to the ground, but at higher levels (some hundreds of metres) our values are rather greater. The reason for this has not yet been elucidated but it may be connected with the fact that the earlier values were derived mainly from diffusion experiments.

Currently in progress is an investigation to explore the possibility of using net radiation data to determine the turbulent fluxes of heat and water vapour from a land surface, for incorporation ultimately in numerical models of the atmosphere. Results to date indicate that these two fluxes can be estimated with quite reasonable accuracy on a 24-hour basis knowing only the amount of available energy together with a reasonable estimate of the surface temperature. For an unsaturated surface some estimate of soil "wetness" is also needed and results so far suggest that the accumulated evaporation since the last heavy rain indicates the degree of drying out with reasonable adequacy. The method is not suitable for use over the oceans because of unknown energy transports in the water itself.

Last year, mention was made of a feasibility study concerning the relationship between concentrations of the natural radon daughters lead-214 and bismuth-214 and atmospheric stability in the lowest layers of the atmosphere. The experimental programme has now been completed and analysis of the data commenced.

Last year's report mentioned the development of a prototype anemometer/wind-vane unit

suitable for small-scale synoptic network applications, in particular for recording the pattern of surface flow associated with thermal convection currents. This unit incorporates low-torque transducers to permit direct DC recording or readout, and can operate at wind speeds down to 30 cm/sec. Construction and field testing of a set of 11 such units has now been completed and it is proposed to use these in an investigation of thermal convection in the near future.

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. Equipment has been designed to determine these quantities, initially over a representative Victorian snowfield, both by the direct means of lysimetry and by indirect means utilising measurements of radiation, windspeed, temperature and humidity.

For snow lysimetry a large beam balance, of over 1 ton capacity, and pan area about 1 m^2, with an accuracy of 0.002" (0.05 mm) of equivalent water depth, had already been tested under rugged conditions at Mt. Buller, Victoria, in 1966. This autumn it was transferred to a more suitable site at Falls Creek, in the same State, in readiness for a programme of measurements this spring.

V AGRICULTURAL METEOROLOGY INCLUDING EVAPORATION

The principal concern of the Agricultural Meteorology Group remains the investigation of exchange processes between the atmosphere and the various types of surface underlying it, in particular crops and vegetation of economic importance. As part of this general aim, a great deal of attention is given to development and refinement of experimental techniques, and especially to the measurement of the vertical fluxes of water vapour and heat.

Work is proceeding on the development of a

comprehensive theoretical model of crop growth in order to investigate the influence of the vertical gradients of radiation, wind speed, temperature, carbon dioxide, etc., set up in the vegetation layer, on the pattern of growth. The model takes a more basic approach than usual. It uses computed data, which can be reasonably regarded as independent, and empirical relationships only when the physical aspects are adequately understood. Using the information on the above-crop meteorological conditions, the initial architecture of the canopy and roots and the initial soil water status, it attempts to predict, amongst other things, the architectural development of the crop both above and below ground.

One interesting feature of the model is that the in-canopy vertical mass transfer coefficient profiles (which largely determine the in-canopy meteorological variables) are predicted theoretically instead of being inserted as data, as is usually the case. The experiment is designed not merely to correctly simulate total photosynthesis of a particular crop but rather to get some idea of the way in which plants develop their own particular physiological responses and physical characteristics as well as understand to what extent plant development in the field is controlled by the physical environment rather than genetic or evolutionary factors. In short, such a model is a good "ideas generator", and as such has already proved invaluable.

Although the work is still in its early stages, it seems that even as a pure simulator the model's performance is equal to, and perhaps better than, that of others commonly in use.

At the request of the New South Wales Water Conservation and Irrigation Commission and the C.S.I.R.O. Division of Irrigation Research, Griffith, Fluxatrons were used to compare evaporation rates from a reed infested swamp with those from a similar nearby body of open water.

The Barren Box Swamp, near Griffith, is a large area of shallow water in which grow dense

"islands" of reeds, known as "cumbungi". The measurements made at the swamp were compared with others made at Lake Wyangan some 16 km away. It became evident that the presence of the reeds caused a significant reduction in water loss, due to a combination of their high albedo, their internal resistance to water transfer and to the shelter they provide for the water surface. In situations such as these, the eddy-correlation technique offers a virtually unique facility for measuring evaporation. Alternative methods rely heavily on knowledge of the energy available for transfer into the atmosphere (which is difficult to determine) or on measurement of water inflow, outflow and seepage all to an unattainable degree of accuracy.

Evaluation has continued of a combination method of evaporation measurement, utilising standard measurements such as net radiation, wind-speed, temperature and humidity. The formula involved takes into account not only the energy available at the surface but also the prevailing diffusion rate through adjacent air layers, by means of an atmospheric conductance, h; and water movement through the soil and plant, by means of a crop internal conductance, h_i.

The relationship of h to windspeed being now reasonably well understood for the crops worked on to date — pasture and potatoes — the emphasis this year has been on relating the internal conductance of these crops to soil moisture content and to several potentially useful indices of plant moisture status.

With pasture, h_i is found to relate quite closely to soil moisture, as well as to plant moisture stress (as indicated by relative turgidity and water potential), but with potatoes, h_i seems less dependent on soil moisture, per se. Nevertheless, excellent relationships have again been found between h_i and plant moisture status, even down to periods as short as an hour.

During the year two models of a relatively inexpensive yet high-performance data acquisition and integration system (D.A.I.S.Y.) were constructed

primarily to facilitate the collection and analysis of data required for combination method investigations. At selected intervals these instruments print accumulated totals of applied electrical inputs: five channels accepting analogue signals in the range 0 - 10 mV, and a sixth recording the total number of pulses generated by a contacting anemometer. Significant features of D.A.I.S.Y. are an output format which makes for easy interpretation and analysis of record, ability to continuously monitor each analogue channel by panel meters, portability and low power requirements. The instrument has proved reliable and accurate in both field and laboratory trials.

In October 1968, jointly with several Departments of Melbourne University, a comprehensive study of the microclimate, water status and growth rate of a barley crop was carried out at the University Experimental Farm at Mt. Derrimut. Over a three-week period, hourly fluxes of radiation, heat, water vapour, and carbon dioxide were recorded, along with the more conventional measurements such as windspeed, temperature and humidity, soil moisture, and so on. Analysis of the large amount of data obtained is still proceeding, but there are already indications of several useful relationships. The experiment is to be repeated this spring, hopefully with an even more complete instrumental coverage.

A new energy-partition evaporation recorder has been designed and constructed on the basis of experience gained with earlier pilot models. Like these, the new instrument 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. Modification of circuitry and layout has improved accuracy, whilst continuous integration of the output, together with automatic hourly printout, has facilitated analysis of results. Operating procedures have been simplified to permit completely unattended operation over periods of up to a week.

Comparative trials against Aspendale lysimeters have been encouraging and further trials at more open sites are planned.

A simple instrument known as an eddy-flux evaporation recorder (E.F.E.R.) is being developed to determine the sensible heat flux entering the atmosphere from a crop surface and thence, via associated energy balance measurements, the latent heat flux — or in effect the crop evaporation rate. In its present form, now undergoing trials at Aspendale, E.F.E.R. operates essentially along the same lines as the Fluxatron (referred to on page 22). Unlike the latter, it gives only an approximation of the true sensible heat flux rather than the actual value at a point above the crop. However, because its sensors are more rapid in response, and therefore able to cope with the smaller eddies important in turbulent transfer near the ground, the point of measurement can be lower down, thereby avoiding much of the effects of advection.

As a further step towards a simple, low cost lysimeter, a pilot model of a new type of lysimeter balance is being built. It is designed to harmonize with the new method of installing monolith lysimeters referred to last year, and should bring the overall cost of lysimeter installation to within reach of most agricultural and hydrological authorities.

VI RADIATION

The net long-wave radiometer mentioned in last year's report has been fully developed and field tested. The instrument is quite simple, and consists of a spherical shell of black polythene (an infra-red transmitting material) spun continuously about an ordinary Funk-type net radiometer. The performance of the instrument is unaffected by variations in short-wave radiation, wind speed or temperature.

An optical filter for absorbing photosynthetically-active (PA) radiation has been developed. The chlorophylls extracted directly from plant leaves are used as absorbing pigments in

a special transparent medium which delays the normal photo-decomposition of the chlorophyll. The filter material can be used to convert ordinary radiometers into instruments responding only to PA wavelengths. (It must be remembered that the definition of PA radiation here is set by the concentration of chlorophyll, and as such is somewhat arbitrary.) Experiments have shown that for clear sky conditions the ratio of PA radiation to total short-wave radiation is remarkably constant. With cloudy skies the ratio varies enormously about the clear-sky value — though the latter is still a good long term average. Measurements of the transmissivities of typical leaves to PA radiation indicate that the quoted values of about 10% are on the high side.

Since February of this year an automatically-recording "uni-directional" form of the radiometer has been installed permanently at Aspendale in order to monitor the downward flux of long-wave radiation from the sky. The clear sky data so far available have been examined and compared with the predictions of an empirical formula developed earlier by Swinbank. The formula appears to overestimate the downward flux during the daytime — typically by 3 to 4 mW cm^{-2} at midday. This could be due to the fact that the formula was based on night time measurements which would be biased towards inversion conditions. A study of the theoretical implications of this same formula has just been completed. It shows that the formula can be derived from existing knowledge of water vapour emission when account is taken of the strong correlation between screen temperature and the amount of water vapour overhead. An analysis of observations suggests that the formula proposed by Elsasser in 1942 in terms of temperature and vapour pressure is of rather wider application.

Work has started on the development of a pyrgeometer, sensitive only to wavelengths from 8μ to 13μ. In this region, clouds and aerosol particles absorb and emit, but there is little absorption from atmospheric gases. The instrument will be used to continuously monitor radiation from clouds and aerosol particles.

The design is based on a thermopile detecting element but instead of the conventional matt black absorbing surface it employs a crystalline slice of material, transparent to all wavelengths less than 8μ. The lower surface is silver-plated in order to reflect shortwave radiation. Crystalline mica is presently used as the transparent medium, but this will be replaced shortly by crystalline magnesium oxide, which has superior qualities. A prototype model, which at present is monitoring total nocturnal cloud radiation, shows promising performance. If successful, the principle will be applied to the conventional net radiometer.

Basic instrumentation for a long path (~50 m) infra-red hygrometer has been built. The equipment is still in the development stage, but ultimately it is hoped to obtain spatially averaged atmospheric humidity figures above various naturally occurring surfaces, and to compare these averages with fixed point measurements. Such an instrument has obvious application where mean values over an area are required.

Equipment for measuring ultra violet radiation on a comparative basis, continues to be operated at Aspendale on behalf of the University of Queensland: it is one of a chain of three instruments, the others being in New Guinea and Brisbane.

In co-operation with the Geography Department of Monash University, some initial measurements of gradients of global and net radiation have been made in a eucalypt forest near Daylesford, Victoria. Simultaneous measurements of the same elements above the canopy are needed to obtain a useful series of data and it is hoped to make these during the coming summer.

Radiation scales as distinct from the International Pyrheliometric Scale 1956 are maintained in many of the National Standards Laboratories of the world. Advantage has been taken of a series of comparisons, recently concluded, of these radiation scales, to relate it to

the International Pyrheliometric Scale 1956 via Ångström Pyrheliometer No. 502 held by this Division and representing the Australian national standard as well as the WMO Region V standard. The scales appear to differ by 1.4%, the value assigned to a given irradiance by the I.P.S. scale being the lower.

In response to an invitation issued through the President of World Meteorological Organization, Region V, New Zealand and the Philippines notified their intention of submitting their National Radiation Standards for comparison with the Regional Standard No. 502. The New Zealand instrument has been received and the comparison satisfactorily completed, whilst that from the Philippines is still awaited.

A limited comparison between pyrheliometers employed as substandards by other organizations, and the Division's Ångström pyrheliometer was carried out during last summer at the laboratories of the Division of Irrigation Research, Griffith, New South Wales. Participants also included the C.S.I.R.O. Division of Mechanical Engineering, the Commonwealth Bureau of Meteorology, and the Meteorology Department of Melbourne University.

The number of calibration certificates issued for radiation instruments in 1968/9 was again substantially greater than for the previous year. Ability to cope with this increase is due in part, at least, to the installation of a Xenon arc short wave radiation source, use of which, for calibrating purposes, has been approved by the National Association of Testing Authorities, Australia. This has removed a former dependence on cloudless days, which, occurring only some seven times a year, have been a bottleneck in the calibration system.

To increase calibration accuracy, a water cooled radiometer enclosure for use with the long wave radiation source has recently been brought into use. It will form part of the semi-automatic long wave calibrating equipment now under development.

One of the Division's Silver Disc pyrheliometers is being modified so that it will operate unattended. Improved precision should result from automatic timing of the shutter movements and it is hoped that the modified instrument will be suitable for participation in future W.M.O. Inter-Regional Comparisons of Pyrheliometers.

VII MISCELLANEOUS

General

The Division is 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 annual calibration rate — which grows continuously — now amounts to over one hundred instruments a year, from both Commonwealth and State Governments as well as from industrial and commercial firms. Improvements in the radiation calibrating procedures are referred to in Section VI.

The computing and data processing group has again assisted in various projects, including the continuing analysis of the Wangara data.

Construction of the new analogue/digital conversion system, mentioned in last year's report, has now reached the first stage of completion, and the equipment is undergoing tests. This system converts data in various forms into digital format, on magnetic tape, suitable for presentation to computers. At present, the system can accept multichannel analogue voltages or magnetic tape, and also chart records, the latter with manual following of one or two traces (later three) simultaneously. It is proposed to extend the equipment to accept data from a typewriter keyboard and from a punched paper tape reader.

Instrument Development

To meet the research needs of the Division, many different types of instruments are designed, ultimately appearing as prototypes in the machine

shop. Of these, some are of interest to other workers both in Australia and overseas, and therefore of industrial value. Where new ideas are involved patents are taken out, but in either case the instrument frequently goes into commercial production.

The development of the Fluxatron, an instrument designed to measure convective heat transfer in the lower atmosphere, has been described in previous reports. This year, the technique has been further simplified by using commercially available analogue multipliers. The instrument now accepts fluctuating DC signals representing any two atmospheric variables and computes the covariance in the relevant frequency band — approximately 0.001 to 0.5 cycles per second.

To prove the instrument, various checks are made on it whenever the opportunity presents itself. By employing the appropriate sensor, the equipment can be operated in a number of modes and the values of a variety of fluxes checked against others obtained through independent measurements. In this way entirely satisfactory comparisons have been made in respect of sensible heat, shear stress and sensible plus latent heats.

Being based on the eddy correlation technique, the Fluxatron is eminently suited to the direct measurement of evaporation. However, a continuing search during the last three to four years for the correct type of rapid response water vapour sensor has failed to bring to light a satisfactory device.

Some years ago the Division developed a standard, heavy duty, 5" cup contact anemometer, with a starting speed of 1 m.p.h. The instrument, which has been standardized on by the Bureau of Meteorology, has now been improved by the addition of a generator-type output without affecting the starting speed. Long term field trials are about to begin.

Reference was made in last year's report to the effect of sea surface temperature on large

scale variations in rainfall in adjacent regions and to progress made in developing the prototype buoys. Three such buoys are in operation, two in Port Phillip Bay some 5 miles off shore, and another 1½ miles off Cronulla, New South Wales. Sea temperatures are obtained twice a day. A fourth buoy is about to be installed near Mt. Gambia, Victoria. This has been improved by the provision of solid state circuitry and a dough-moulded fibre-glass body; the latter simplifying manufacture, increasing the strength and reducing the cost.

For the study of the structure of turbulence in the wind over the sea, a special spar buoy was constructed to provide an almost stationary mast 6 m high on which to mount sensing elements. After trials in Port Phillip Bay and at sea, the buoy was dispatched to the Barbados to be used in the BOMEX expedition staged by U.S.A. to study many aspects of air-sea interaction.

The long period recorder developed by this Division has now completed 10 years of commercial production. Unfortunately the batteries originally selected to drive the recorder are no longer available from local sources, and the imported substitutes, being older on arrival in the country, tend to deteriorate too quickly to be of use. A new model has therefore been developed to operate on locally made lower voltage batteries. Advantage has been taken of the changeover to mount the batteries and those parts of the instrument sensitive to extremes of temperature and humidity in a hermetically sealed container, which is installed underground where temperature fluctuations are severely damped.

Minor developmental work on the hydraulic/pneumatic lysimeter referred to in last year's report continues. Success has been achieved with a rectangular soil container, which is required when dealing with row crops.

Out of the convection experiments referred to elsewhere in this report a need arose for a low torque wind speed and wind direction recorder. In the case of the former, an existing generator-type

anemometer with a stalling speed of some 30 cm/sec has been modified by adding a further three cups. The additional cups make possible a low starting speed, as well as help to impart a smooth torque and thus reduce fluctuations in the electrical output. Small changes in wind speed direction are sensed by means of a lightweight, balanced, expanded polythene vane, mounted on jewelled bearings and actuating directly a low torque precision potentiometer. Electrical output of the latter is fed on to magnetic tape, and the unit responds to wind speeds as low as 30 cm/sec.

A third instrument for recording air flow in both horizontal and vertical planes has been devised along similar lines to the wind direction recorder just mentioned, wind 'direction' being sensed by the same type of vane used previously but mounted on a horizontal axis. The unit is maintained into wind and electrical take off is via slip rings. Again the threshold is 30 cm/sec.

Equipment used to record rapidly fluctuating signals, for example of temperature and water vapour, is frequently expensive and not suited to field work. Recently, a system based on a commercial tape recorder was built. It records the output of up to three sensors in analogue form, and on play back, the data can either be spectrally analysed using a completely analogue system, or digitized automatically for normal computer use. Whilst it lacks the accuracy of a sophisticated unit, the quality of its output is sufficient for many purposes; moreover, it is simple, portable and low-priced.

VIII ACTIVITIES AND PERSONALIA

Late in March, Cabinet approval was given to the establishment of a new Commonwealth Meteorology Research Centre as a collaborative arrangement between the Bureau of Meteorology and the Division. The work of the Centre will consist of studies of the behaviour of the earth's atmosphere, with emphasis on general circulation, directed towards improvement in understanding the distribution and variations in climate on the earth,

and towards improvement in the accuracy and time-scale of weather forecasting.

This will include the formulation and testing of numerical hemispheric models, and the modelling of circulations of a more regional type. The approach to these problems will, as desirable, develop the interpretation and use of new forms of observational data. The Centre will not, however, undertake responsibility for observational programmes.

The Centre will be located with the Bureau of Meteorology's premises in Melbourne, and both the Division and the Bureau will allocate staff. Dr. G. B. Tucker has been appointed to the position of Officer-in-Charge. In future years, annual reports of the Centre will be issued in conjunction with this report.

During the year Dr. G. W. Paltridge, and Mr. J. A. Lane* were jointly awarded the Institution of Electrical Engineers' Marconi Premium for a paper entitled "Small-Scale Variations of Radio Refractive Index in the Troposphere: Part 1 - Relationship to Meteorological Conditions, and Part 2 - Spectral Characteristics. This is awarded annually for the best contribution to the Proceedings of the I.E.E.

In January, the Chief of Division, Dr. C. H. B. Priestley, attended the second session of the Joint Organizing Committee of the G.A.R.P. (Global Atmospheric Research Programme) at Princeton, U.S.A. At the same time he attended a meeting of the IAMAP/IAPSO/SCOR Joint Committee on Air-Sea Interaction, also at Princeton.

By invitation from the Agricultural Bureau of South Australia, Dr. Priestley delivered the Thirteenth Agricultural Bureau Oration in Adelaide in September 1968. During this visit he also presented the 1968 Einstein Memorial Lecture at the invitation of the Australian Institute of Physics.

Footnote *of the Radio & Space Research Station, Slough, England.

In August 1968 Mr. E. L. Deacon returned after a ten-month absence as Visiting Professor at the Department of Meteorology, Texas A. & M. University, and in October he attended a symposium on Air-Sea Interaction at the Institute of Oceanography, Vancouver, Canada.

Dr. A. J. Dyer returned to Australia in December 1968 after spending six months at the Department of Atmospheric Sciences, University of Washington, U.S.A. En route he visited meteorological institutions in the U.S.A. and the United Kingdom.

In September 1968 Dr. R. N. Kulkarni attended the 1968 Ozone Symposium held in Marseilles, France. He also visited principal centres conducting ozone research in France, U.S.A. and the United Kingdom.

In July Dr. P. Frenzen of the Argonne National Laboratory joined the Division for a period of nine months. His principal interest is the structure of atmospheric turbulence.

Dr. H. C. Martin, who has spent two years in the Division working on the fine structure of atmospheric moisture, returned to Canada in October 1968 to take up an appointment with the Meteorological Branch of the Department of Transport, Toronto.

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