ANNUAL REPORT 1971-72

Division of Atmospheric Physics

Commonwealth Scientific and Industrial
Research Organization, Australia
Melbourne

CONTENTS

DIVISION OF ATMOSPHERIC PHYSICS

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I INTRODUCTION

General

To mark the 25th anniversary of the foundation of the Division, achieved this year, some brief general stock-taking comments may be appropriate. The role of the Division remains, as it was at the outset, that of conducting basic research into the physical processes underlying and controlling the weather and climate. Progressively, however, the details of the work have undergone change. These changes have stemmed from two causes. The internal causes are common to all research organisations and are generated by changes in the 'state of the art' or the science itself, the ripeness of different areas for advance, new avenues opened by technological developments, etc. External causes derive from the national and regional, etc., situation. The atmospheric problems highlighted by an advanced, industrialising community will differ in emphasis from those which are of greatest concern to a less advanced or predominantly rural country.

In most cases, however, such changes in emphasis have not called for new activities in new scientific areas, but rather for a new blending from the fundamental components of atmospheric science - synoptic meteorology, fluid dynamics, turbulence, cloud physics, radiation, mass transfer, phase change, etc. These central themes have not changed. The Division chose originally to organise its work round these themes, blending from each as appropriate to meet specific practical problems. This policy, as opposed to that of organizing with respect to a

specific application or end-product, is believed to pay the greater dividends, practical as well as scientific, in this area of research.

Our successive annual reports have been prepared with emphasis on the scientific developments as against the ad hoc applications, and have accordingly been structured, like the work itself, in terms of the basic components. Thus their general framework has changed but little, apart from the evolutionary expansions and additions. Readers more interested in the applications of the work than in its scientific content are referred to a paper published this year (Priestley, 1972) which reviews the wide diversity of practical community problems to the solution of which the work has contributed.

A specific illustration of re-blending to meet changing external needs is reflected in our programme and the problems of the environment as related to air quality and human welfare. This is apparent in the details of the work but, as anticipated, many pre-existing fundamental studies are required to compose the new recipe. Much of the knowledge gained from the research on turbulence, on radiation, on synoptic meteorology, is basic to the air pollution problem. Ozone has been studied for many years as a trace element indicative of stratospheric transport mechanisms: now the knowledge of its distribution and source-sink mechanisms is of much more immediate practical concern in the context of supersonic aircraft and the possible modification to the intensity of ultra-violet radiation reaching the earth.

Among the areas which are currently receiving more emphasis in the Division's work are the following:-

a) Atmospheric radiation, including the radiative properties of clouds. There are large and important gaps in our knowledge of the atmospheric radiative balance. This ignorance is one of the limiting factors in the development of numerical models of complete atmospheric behaviour.

b) Laboratory models using tanks of density stratified fluid to simulate a variety of atmospheric phenomena. Such controlled experiments provide insight into dynamical processes which occur in the free atmosphere.

c) Air-sea interaction. Air-surface interactions govern many atmospheric processes and three-quarters of the earth's surface is covered by water. Practical difficulties in conducting experiments in the past have impeded the rate of development of these studies.

d) Carbon dioxide monitoring, in the global context. The growth of carbon dioxide content of the atmosphere is capable of causing significant climatic change. There is currently a dearth of high quality monitoring stations, especially in the Southern Hemisphere.

Organizational Changes

A recognition of the advantages of greater co-ordination of those CSIRO groups whose work is related to problems of the atmospheric, etc., environment has led to the creation of the Environmental Physics Research Laboratories. Together with this Division, they comprise the Division of Environmental Physics in Canberra, and the Cloud Physics Section, formerly of the Division of Radio Physics, in Epping, N.S.W.

Dr. C.H.B. Priestley has been appointed Chairman of the Laboratories but has continued as Chief of Division for the current year.

As an interim measure, the Cloud Physics Section has been attached to this Division for the past 12 months: its report of work for this year therefore, will be found in these pages. On July 1st, 1972, the Cloud Physics Section became a Division in its own right, as one of the three component Divisions of E.P.R.L.

II DYNAMICAL AND SYNOPTIC METEOROLOGY

For some years now, there has been a growing interest in the development of models to simulate, and thus be able to predict, global scale motions and fields of temperature, cloud and precipitation. One of the ultimate aims is that of predicting the climatic effects that may result from changes in atmospheric composition arising from man's activities.

The main part of this large-scale numerical modelling research is carried out in the Commonwealth Meteorology Research Centre. See Section IX. However the numerical work is limited by important gaps in our knowledge of the physical processes occurring. Some of these gaps can be identified as belonging to the areas of small scale turbulence and the processes of convection and cloud formation. An important extension of these studies has led us to consider the whole atmospheric boundary layer, a kilometre or more in thickness.

The Boundary Layer

The relevance of boundary layer studies in larger scale numerical models is to learn how to represent the vertical fluxes of momentum, heat and moisture in terms of large scale parameters. The approach from similarity theory initiated by Kazansky and Monin, based on certain simplifying assumptions, derives a form of relationship between the fluxes at the surface of the earth, the conditions at the top of the boundary layer, and the latitude and condition of the surface. Four undetermined parameters A, B, C, D, (for fluxes of momentum, heat and water vapour) result from the theory, and these must be estimated experimentally or by further theoretical considerations.

Experimentally, parameters A, B and C have been determined from the data collected during the 1967 Wangara field experiment at Hay, N.S.W. However, as with other attempts, this analysis resulted in a large degree of scatter.

A theoretical study of the equations of motion

and the lower boundary conditions, has identified the (constant) value of B in a neutral, baratropic atmosphere as $3\pi/2$, and showed that both A and B, for neutral stability, are quite sensitive to even small degrees of baroclinicity (variations of density in the horizontal). At this stage, A cannot be uniquely determined but requires some additional condition, e.g. an upper boundary condition. The large experimental scatter is probably due to the sensitivity to departures from strict barotropy and to other departures from ideal conditions assumed in the basic theory. A valuable extension to this theory has for the first time made quantitative predictions of the effects of baroclinicity.

A different approach to boundary layer studies is necessary when modelling on a scale much smaller than the global, when it may be necessary to reproduce the boundary layer in some detail. Under these conditions, the assumptions of similarity theory are often violated.

In this approach, it is usual to prescribe an eddy coefficient or a mixing length for vertical fluxes in terms of the internal characteristics of the boundary layer. A number of such ways of prescribing the results of turbulence has been tested against the Wangara observations, and their value assessed by the quality of the simulations obtained over the course of a day, with known heat input and surface roughness. Variables in the simulation are wind components, temperature and humidity, and momentum and heat flux at the surface. Improved ways of linking the height and time dependent fluxes to ascertainable variables in the boundary layer are being explored.

Seabreezes

Sea breezes influence the daily life of the majority of Australians, and have important balancing effects on the energy and water vapour regimes of the Continent. It is estimated that 20 per cent of the heat energy ($8\text{-}9 \times 10^{13}$ Megajoules) absorbed by the atmosphere each day over Australia in summer, is exported seaward by seabreeze processes.

The daily import of water vapour is computed to be of the order of 2×10^9 tons (2 per cent of the vapour over the Continent), enough to provide about .01 inch of rain everywhere.

Numerical seabreeze models embodying the best boundary layer formulations so far discovered, have been set up to study these processes in detail. Comparison of the model results, with available observations suggest that the modelling is very successful. A seabreeze front forms in the early afternoon at 20-30 km inland, and propagates further inland during the afternoon and night, reaching maximum intensity about nightfall, after which it slowly decays. A series of numerical experiments suggest that modifying effects of large scale pressure gradients are quite strong. An onshore gradient wind weakens but does not destroy the seabreeze front, and causes it to propagate inland more rapidly, while an offshore gradient wind has reversed effects so that the front, although sharper, may be severely limited in its inland penetration.

The effect of topography in the hinterland is also being investigated. It appears that the presence of an escarpment inland intensifies and delays the inland spread of the seabreeze, as is observed for example in the Canberra area.

It is hoped to extend the modelling to cover cases when cloud and precipitation can occur, since the seabreeze front is known to have important effects on these in some locations.

A further extension of the model would be to the development of tropical cyclones, and although difficulty is experienced in adequately treating moist convection - an essential ingredient of cyclones - it is hoped that simulated cyclone development will shed some light on the generation processes which produce this important phenomenon.

Laboratory Atmospheric Models

Development work continues on facilities for the laboratory simulation of atmospheric phenomena,

using salt-stratified water as the working medium. The most recent addition is apparatus in which an accurately controlled linear velocity (constant shear) profile of flow can be sustained for a useful experimental period, in a continuous stable stratification.

The apparatus will be used in quantitative basic studies on the interaction and absorption of the momentum of internal gravity waves by a prevailing horizontal flow. It is believed that a significant proportion of the momentum exchange between the Earth and the atmosphere is accomplished through such interaction, the waves being generated by mountains or by underlying convective activity. A detailed knowledge of the kinematic structure, as sought from this apparatus, is needed to evaluate existing theoretical models and assist in the more reliable formulation of new ones.

Angular Momentum Mixing

Relative to an observer in space, most of the Earth's atmosphere rotates, on average, faster than the Earth itself. In other words, the globally averaged wind direction is westerly.

Only a small part of this relative motion can be accounted for by the steady exchange of air between the low latitudes, where angular momentum is highest, with air from higher latitudes. Indeed, in the middle latitudes this steady exchange takes place in the wrong direction.

This phenomenon can be qualitatively explained if the atmospheric eddies behave not in the manner of molecular viscosity (which always acts to diffuse or reduce gradients of relative motion), but acts to mix or reduce gradients of relative angular momentum. Although there is abundant evidence in nature that this is what happens, and computer atmospheric circulation calculations show the same effect, previous laboratory attempts to simulate the phenomenon have been unsuccessful.

A new experimental approach making use of Monash University Geophysical Dynamics Laboratories'

turntable has now resulted in a successful demonstration. Strong cyclonic vortices (evidence of diffused angular momentum) can be induced within a completely filled uniformly rotating cylinder of liquid by the forcing of inertial waves which 'break', to produce turbulence (see figure 1). Before the fluid becomes turbulent, the rotation remains uniform, indicating that it is the turbulent activity which accomplishes a diffusion of angular momentum.

The technique provides means of evaluating the efficiency of mixing and of studying the structure of turbulence in the presence of rotation.

Internal Wave Interaction

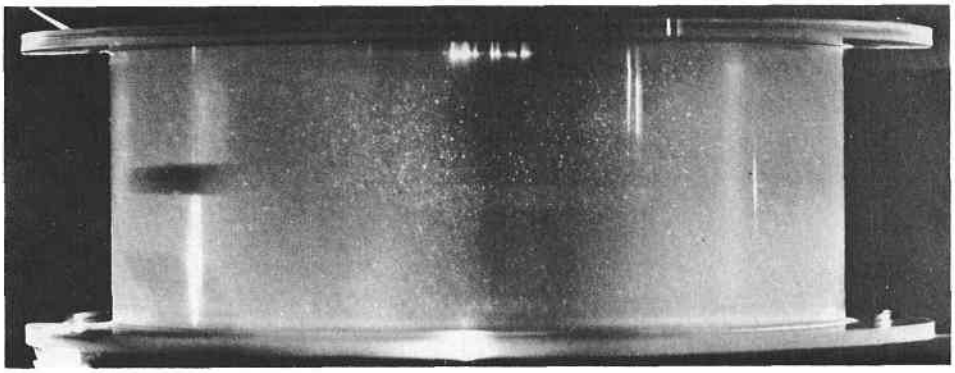
Further work has been directed to the mechanics of internal wave degeneration in a continuous stratification. A single plane wave can commonly be the highest frequency member of a 'resonant triad' of waves. If this wave is forced above a certain critical amplitude the other 'parasitic' members proceed to extract energy from it.

The observed susceptibility for internal waves, in nature and in laboratory experiments, to suffer these unstable interactions is accounted for by the plurality of possible triad partners. The consequences of having more than one triad initially present and sharing the forced wave, has now been investigated theoretically and simulated experimentally. A remarkable result is that regardless of the energy supplied, the forced wave ultimately attains a constant (low) amplitude, all the remainder of the energy passing into the interacting triad members. Furthermore, these parasites ultimately reduce in number to two.

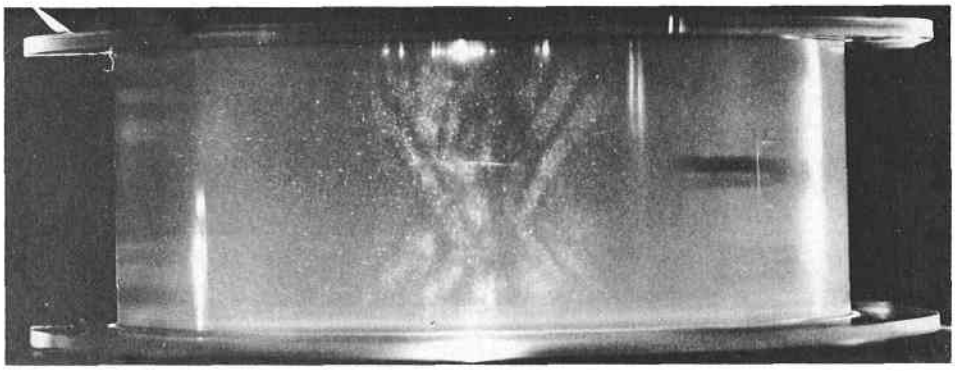
An implication of these results to be further studied is that a spectrum of internal wave energy in a stable stratification for a given input or initial conditions, may be analytically derivable.

General Circulation and Climate

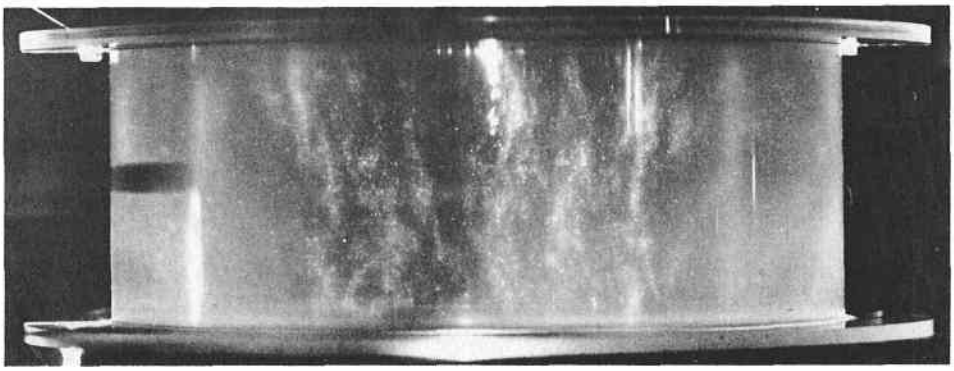
The relationship between local climate and



(a) Before excitation is commenced all the liquid is in uniform rotation.



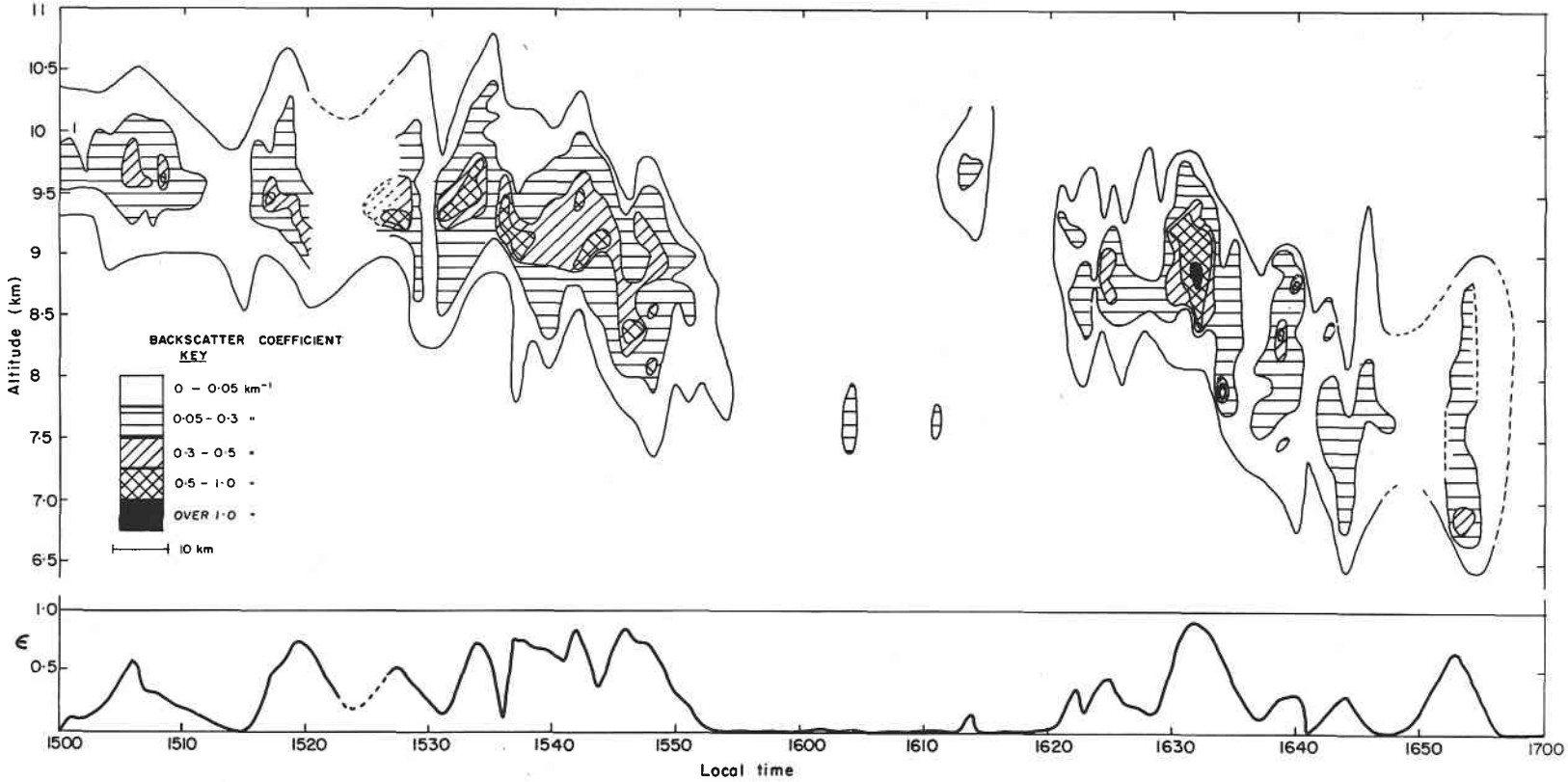
(b) Excitation has commenced. A complex system of interacting waves is developing.



(c) These waves break into turbulence and a cyclonic vortex immediately forms.

LABORATORY DEMONSTRATION OF ANGULAR MOMENTUM MIXING

These photographs show a transparent cylinder completely filled with liquid, rotating about a vertical axis. Fine pearlescent powder in suspension reveals internal motion. Turbulence is induced by exciting 'inertial' waves, and the formation of a vortex demonstrates that angular momentum has been mixed.



The change in lidar backscatter coefficients from a cirrus cloud in the zenith as the cirrus drifted across the observing site, and the corresponding change in the infrared emissivity ε.

the general circulation can be examined using correlations between year-to-year variations in local climatic elements and indices of the general circulation. A convenient index of the general circulation is the mean latitude, L, of the surface high-pressure belt, which is related to the onset of baroclinic instability in the main zonal flow.

In addition to the correlations found between L and total ozone, stratospheric winds and temperatures which were reported last year, significant correlations have been found between L and district mean and individual station rainfall.

Australian data shows significant positive correlations between L and rainfall along the east coast, and equally significant negative correlations for south-western and south-eastern Australia. The index L can in fact be used to explain more than one-third of the year-to-year variance in rainfall over appreciable areas of Australia, while local spatial variations in the correlation coefficient clearly reflect the interaction of various orographic features with the general circulation.

Climatic trends which involve systematic trends in L, will thus manifest themselves in different ways at different localities, depending on the orography. Using observed correlations between L and single station rainfall, it is thus possible to predict and quantify degrees of local orographic influence on climatic elements. It may thus eventually become possible to distinguish some natural changes from local changes in precipitation which may result inadvertently from industrial or other activities of man. A study has commenced of North American data which aims at testing the feasibility of using such an approach.

The inter-relation found between L and various other features of the general circulation and climate may have important implications for theories of climatic change, the quasi-biennial oscillation, and the future development of a long-range forecasting capability.

III RADIATION

Solar radiation provides the energy which drives the circulation of the atmosphere and oceans. Its influence depends on both the quantity and location of absorption. Absorption in the upper atmosphere may have very different effects on climate to absorption in the lower atmosphere or in the oceans. Thus the attenuation of both short wave (solar) and long wave (infrared) radiation by the atmosphere and the manner in which this is influenced by atmospheric constituents such as cloud, dust and water vapour, requires to be fully understood in order to describe the energy inputs to the atmosphere. Our inability to do this accurately enough is at present one of the limitations to the performance of models.

The radiation group has been concerned with the effect of clouds on the radiation climate and vice versa. The group has continued to accummulate atmospheric turbidity measurements for the purpose of monitoring changes in the absorbing properties of the atmosphere which may result from changes in atmospheric constituents, whether natural (e.g. volcanic dust) or man made.

Radiative Properties of Strato- and Altocumulus Cloud

This year, during a 3 week expedition to Coff's Harbour, N.S.W., the Cloud Physics Groups' D.C.3. aircraft was instrumented to measure both the upward and downward fluxes of short wave (0.2 - 2μm) and long wave (2 - 200μm) radiation as well as the intensity in the water vapour infra-red absorption spectrum "window" (10 to 12μm). The aircraft was also equipped to measure many of the micro-physical characteristics of clouds such as water content and drop size distribution. The objective was to investigate stratocumulus and altocumulus clouds that were sufficiently uniform and extensive to test various theories of cloud scattering and absorption. It is hoped that further information can be obtained in a repeat expedition, thus enabling a start to be made on a catalogue of the radiation and micro-physical climate of various cloud types.

Radiative Properties of Cirrus Cloud

Cirrus clouds, composed of ice-crystals, have different optical properties from water-droplet clouds and their radiative effects appear to be a significant element in the global heat balance.

A further programme of observations was carried out with the co-operation of the Physics Department of the University of Adelaide. Our 10-12μm infrared radiometer was again used simultaneously with the Adelaide Lidar facility operating at 0.69μm. Cloud thickness, density and infrared emissivity was measured as before with the addition of an experiment in which a polariser was used at the laser receiver in order to detect depolarised light in the return signal. It was found that cirrus clouds depolarise the laser pulse whereas water clouds apparently do not. This phenomenon has also been reported by workers in the U.S.A.

Analysis of the results of a similar programme in 1970 having been completed, a simple model of absorption and extinction in a cirrus cloud has been developed. This relates the total lidar backscatter integrated through the cloud to the cloud infrared optical thickness. The experimental data agree well with the model and a high correlation is found between the lidar and infrared data. The deduced cirrus backscatter coefffcient at 0.69μm is lower than that for equivalent ice spheres and it is concluded that a cloud of irregular ice crystals will backscatter less than do spheres, which scatter more strongly in the back (180°) region than in other directions.

The lidar backscatter amplitudes have also been corrected for absorption of the laser pulse on the basis of the above model. A plot of cirrus backscatter amplitudes and their variation in the zenith with both height and time is shown in Figure 2, for lidar profiles taken at minute intervals. Several such plots are available for comparison of cirrus evolution under varying synoptic conditions.

An encouraging aspect of the technique is that a short-wave optical thickness can be obtained, and this with existing theoretical treatments gives the cirrus albedo for incoming solar radiation. From there, it should be possible to estimate the total effect of the cirrus on both the long-wave and short-wave radiation budgets.

Radiation Absorption by Water Vapour

Shortwave absorption: One of the major sources of heat to the atmosphere itself is the solar radiation absorbed directly by water vapour. Existing estimates of this absorption available in the literature differ significantly.

During the Coff's Harbour expedition the opportunity was taken to obtain the first direct experimental relation between water path in the atmosphere and solar radiation absorption. This relation confirmed one particular theoretical treatment of the problem (that of Yamamoto) and has gone a considerable way towards resolving an argument of long standing.

Longwave (10-12μm) absorption: Investigation of the water vapour absorption in the 'atmospheric window' from 8-13μm has been continued. Last year it was reported that the water vapour absorption coefficient appeared to vary with water vapour content. Two investigations, one in America and one at Oxford, England, have further confirmed this dependence. The picture that is now emerging is that absorption is predominantly due to the water 'dimer', an aggregation of two water molecules. It is the increase in the number of this species with increasing moisture content of the atmosphere which is now thought to cause the apparent increase in water vapour absorption coefficient in this wave-length region.

In February 1972, our 10-12μm infrared radiometer was taken to Darwin where the clear sky emission was measured under very moist conditions. The dependence on water content of the absorption coefficient was confirmed by comparing the clear sky emission with computed values using local

aerological data. Very high emission values were recorded.

Further measurements were secured on the Coff's Harbour expedition mentioned above. At high altitudes in dry air the absorption coefficient was quite low, as expected, and fit the above mentioned model quite reasonably. Shortpath measurements will be used to develop the model further, as some weak water vapour absorption lines also occur in this region.

Radiative Properties of Atmospheric Dust

Currently one of the important questions in atmospheric radiation is whether natural and man-made dust in the atmosphere scatters away from the Earth more solar radiation than it absorbs. Scattering tends to cool the earth-atmosphere system, whereas absorption tends to warm it, and it is necessary to know which effect is dominant as far as aerosols are concerned. While at Coff's Harbour there was a day of exceptionally high atmospheric dust loading (visibility less than 0.5 km and the layer extending to an altitude of 2 km) followed by a very clear day for comparison. It was possible to obtain complete radiation profiles on both days, which showed that for this particular 'continental dust' the scatter dominated the absorption.

Results of the continuing work on the application of radiation studies to atmospheric turbidity are listed under "Quality of the Environment", page 21.

Radiation Input to Australia

The net radiant energy (incoming minus outgoing) at the top of the atmosphere is the ultimate source of energy for atmospheric motions, and it is important to be able to calculate this quantity with a spatial resolution at least comparable with that used in mathematical models of the atmosphere which are now being developed.

The balloon and aircraft experimental work of the Division over the past few years has yielded

various relations between cloud amount (and height) and the radiation fluxes at the top of the atmosphere. Using these relations and extensive data on cloud amount, seasonal average contour maps of the radiation input to the atmosphere over Australia have been produced. These maps are quite interesting in themselves - they reveal, for instance, that during summer the maximum energy input occurs over the SE and SW of the continent. More importantly, the values compare well with satellite data which gives confidence that the computation technique is valid and can be relied on for use in mathematical modelling.

Instruments and Calibration

Studies of the heat budget at the air-sea interface are facilitated by a knowledge of the gradient of short-wave radiation below the surface. A pyranometer has been modified to measure under-water irradiance in both upward and downward directions. Some initial measurements have been made at several spots in Port Phillip Bay, and gradients at depths down to about 7.5 m have been obtained. Extension of this work is planned for the coming summer.

A programme of interchanging net pyrradiometers with the Canadian Atmospheric Environment Service for cross-checking of the respective calibration standards has been initiated. So far the results obtained have shown good agreement, which inspires confidence in both sets of equipment. Details of our N.A.T.A. calibrating service can be found on page 41.

IV MICROMETEOROLOGY

Air-Sea Interaction

Air-sea interaction has been a continuing area of study, with effort spread over several problems of interest. An analysis of the wave and surface drag properties of the sea, using data obtained by Imperial College, London, over Lough Neagh, Northern Ireland, has continued. A set of empirical relations have now been derived to

describe the parameters of the wave system. The analysis has shown the dependence of aerodynamic roughness of the sea surface upon both wind speed and fetch.

Fetch defines the degree of wave development, but only weakly effects aerodynamic roughness; for example, an increase of two orders of magnitude in fetch causes an increase of about 20% in drag coefficient.

Another feature suggested by the data is that a surface with moving roughness elements can produce a drag less than that over an aerodynamically smooth rigid plate.

In the past few years the Division has carried out several experimental programmes over water surfaces. Fluxes of momentum, sensible heat and water vapour have been measured over water of varying depth. The data show that the water behaves as if it were open ocean (in respect of surface drag coefficient) when the depth is greater than about 7 m. Of great interest is a study conducted in co-operation with the University of Papua and New Guinea over a tidal coral reef south of Port Moresby. The drag coefficients measured over the reef do not show the increase with wind speed which is normally associated with deeper water. This suggests that, in the present context, surface waves of length greater than about 3 m or of amplitude larger than about 20 cm are necessary for a water surface to behave as if it were open ocean.

An examination of the velocity with which oil drifts on the sea surface has revealed a significant difference between the behaviour of crude oil sludge and of small free surface floats. To date, observations on the drift of such floats have been widely accepted as applicable to oil spills. Theoretical examinations of the surface drift phenomenon have highlighted the uncertainty of laws that determine the variation with depth of the wind drift current in the ocean. Measurements are planned to clarify the magnitude of the surface "roughness parameter" of the water flow when there is equilibrium between wind and sea state.

Following on the determination of the relationship between geostrophic wind (determined by the isobars) and the drift of the surface layer and matter absorbed at the surface, statistics of the dispersion of such material in Australian waters are being calculated. Such data are relevant to the movement of certain forms of sea life, and are basic to the practical aspects of siting oil installations or planning protective action against accidental oil spillage.

The ripples (capillary waves) on the sea surface are thought to play a dominant role in both the rate of transfer of momentum from the wind to the sea and also in determining the depths of layers over which the momentum appears as a current after passing through the wavy structure of the surface. Advantage has been taken of the loan of a 3 cm radar with frequency modulation from the Division of Entomology to probe some directional characteristics of ripples of about 1.5 cm wavelength, on the sea surface.

Thermal Convection

Previous years' reports have mentioned a comprehensive field experiment at Hay, N.S.W., in February 1970. Its purpose was to gain a better understanding of the structure of convection in the lower atmosphere, and in particular to investigate how the surface layer (heights up to about 30 m) couples with the larger-scale thermals which extend up to hundreds or thousands of metres.

The investigation is of a basic nature, but the results are expected to have practical application in a problem which is important for numerical forecasting - that of expressing the surface fluxes of heat, water vapour, and momentum in terms of larger synoptic scale parameters. Though the measurements were made over land, convection also prevails over the sea when the air is cooler than the water, and the results should be equally applicable in this wider context.

Measurements included the means and turbulent

fluctuations of velocity components and temperature up to 32 m. Thermals passing across the site were tracked in turn by gliders circling at heights between 300 and 1500 m, the glider position being continuously monitored on the ground by two azimuth recorders. The pattern of surface air flow was recorded by an array of seven wind speed/direction instruments set at 100 m intervals across the wind direction.

From detailed analysis of the results carried out so far, a picture of the form and driving mechanism of thermals is emerging. One question has been whether thermals have a sustained structure and are continually fed from near the ground as they move along, or whether they break away from the surface to become independent rising "blobs". The surface flow patterns strongly support the former alternative, as they show a pronounced relative inflow behind and often ahead of the thermal, the associated wind gust or lull generally lasting for one or two minutes. It appears that there is also significant lateral flow, but clarification of this in the overall picture of a thermal awaits further analysis for occasions when thermals passed abeam of, rather than directly over the experimental site. It is anticipated that the full analysis will be completed in the near future.

Theory of Diffusion from Surface Strips & Rectangles

In many practical situations, micrometeorological measurements are made over a particular surface, for example a lake, an irrigated crop, or a patch of some evaporating substance spread on the ground. Generally these are concerned with a diffusing entity such as heat, water vapour, CO_2, etc., and, with limited upwind fetch over the surface in question, the problem arises of incomplete adjustment for the diffusing quantity. Last year's report mentioned a theoretical treatment of the problem, which gives solutions for the modification of the concentration and flux as functions of fetch and height. In the case of successive surface transitions, and in particular the case of a cross-wind strip, the solution can be obtained simply by

superimposing those for the separate transitions.

The solutions contain an integral which is very difficult to evaluate directly, and a numerical method has been developed. This method has now been further improved, using rational approximations and contour integration.

The theory has now been elaborated to treat the diffusion from a semi-infinite strip of finite lateral width. The diffusion from a rectangular area then follows simply by superimpsing solutions starting at the upwind and downwind edges.

It remains to carry out numerical evaluations of the solutions to obtain concentration and flux for a representative selection of the parameters (normalised fetch, lateral position, and height). The best numerical method for the complicated double-integral has yet to be finalised.

Instrumentation

The Division has now developed considerable expertise in the field of eddy-flux measurement, by which atmospheric fluxes near the surface are computed from fluctuations in the vertical wind velocity and in other parameters. For example, the evaporation rate from a surface is obtained by measuring the variations in humidity near the surface, multiplying these by the associated fluctuations in vertical velocity, and taking a time average. The Evapotron was an instrument designed specifically to fulfil this requirement, and later simplifications and improvements resulted in the development of the Fluxatron. Over the last year, further improvements have been made to the sensors and to the electronics. Field tests conducted over a forest have shown that the new instrument performs significantly better than earlier models, with lower errors and much reduced drift. Circuitry is smaller and lighter, utilising printed circuit techniques and the latest high performance operational amplifiers. The new sensor arrangement is cheaper and more trouble-free, sacrificing none of its sensitivity. The readout still employs sensitive DC motors as integrators, but as a separate unit so

that the operator can replace the motors by digital or analogue devices as required, or may store the output directly on magnetic tape for later analysis.

A study of propeller anemometer performance verified that such devices are suitable for most eddy-correlation work provided that some high-frequency loss can be tolerated. In practice this means that, operating at a height of five metres above a surface, corrections of the order of 8% need to be applied. The calibration coefficient of propeller anemometers is a function of wind speed, and of the orientation of the sensor, so that great care must be taken when using them.

Measurement of evaporation from natural surfaces has been made much easier following the development of an infra-red absorption instrument for the fast-response detection of fluctuations in humidity. The new instrument has been operated successfully in a field trial conducted in co-operation with the Flinders University of South Australia, at Mt. Gambier.

V QUALITY OF THE ENVIRONMENT

Questions of increasing public concern are the degree to which human activity is affecting the composition and properties of the Earth's atmosphere and the climatic changes which might come about from the resultant alteration of the global radiation budget. In most instances the rates of global and regional increase of an atmospheric pollutant, gaseous or particulate, are unknown; or, if approximately known over a short present period (as with CO_2) the cause of the change cannot be uniquely identified, so net future trends are uncertain. Again, while the potential climatic effects could be serious, even disastrous, the problem is one of extreme complexity with, currently considerable diversity of opinion. These are perhaps the most challenging set of problems confronting workers in atmospheric physics today, and their possible urgency makes steadily increasing demands on our attention.

Atmospheric Carbon Dioxide

During the year, a survey of the literature on global aspects of carbon dioxide was completed, with the conclusion that present evidence is not sufficiently compelling to relate all of the observed trend in increasing CO_2 concentrations to increased combustion of fossil fuels, or even to be certain that such trends will continue. To avoid false interpretation of these trends more monitoring stations distributed around the globe are urgently required. Aspendale has met the particular need for a mid-latitude monitoring centre in the Southern Hemisphere, by the initiation of a CO_2 monitoring programme. To avoid extremes of local influence such as urban pollution, air samples are collected from aircraft and are analysed at the laboratory. A similar programme has been going on for ten years at the Institute of Meteorology, Stockholm, and has yielded data agreeing with those obtained at the ground monitoring station at Mauna Loa, Hawaii.

The CO_2 measurement relies upon the comparison of each sample with reference gases, using an infra-red gas analyser. Preliminary data from the middle troposphere over Bass Strait show remarkably little variation in concentration (± 0.5 ppm) from week to week over an initial three month period. Vertical differences between the mid- and upper troposphere (5 to 12 km) are about 1 ppm and variations over horizontal distances of hundreds of km are of the order tenths of a ppm.

Through the good offices of Qantas and the Department of Civil Aviation aircraft sampling is now a matter of routine. TAA will shortly be assisting in the same manner. Automatic sampling equipment will be installed shortly in other commercial aircraft, and balloon sampling is anticipated for later this year. Exploratory investigations of this type are of considerable interest in themselves but are also a necessary pre-requisite to determine the pattern of a permanent monitoring programme.

Air samples have also been collected from

Atmospheric monitoring: radioactivity and particulates.

CO_2 measurement in the free atmosphere - equipping the aircraft.

light aircraft flying at low levels over suburban Melbourne. Together with measurements made at ground level at Aspendale, these suggest the urban ground level sources and sinks affect the CO_2 content significantly over a depth related to the height of the inversion layer - at the time about 100 m.

Near Surface Ozone

Measurements of ozone in the surface air continue at Aspendale, Macquarie Island and Darwin, with the co-operation of the Bureau of Meteorology and the Antarctic Division, Department of Supply. Also, measurements were commenced at Robertson, N.S.W. in conjunction with a programme operated by the Cloud Physics Section. Brewer continuous bubblers are used at all sites and Ehmert sensors are also used at Aspendale and Macquarie Island. A three day comparison made between the Ehmert sensor and the Komhyr ozone sensor (used by the United States National Oceanographic and Atmospheric Administration) showed the instruments to be comparable within an acceptable level of about one percent.

Studies of ozone in the unpolluted atmosphere have continued. A joint study, with the Antarctic Division, completed during the year, indicated that hitherto unknown processes of absorption and emission of ozone may occur at snow surfaces. The long series of ozone observations at Macquarie Island is being analysed in an attempt to clarify the role of meridional circulation in the tropospheric mixing and transfer of ozone. This work may help in understanding its relationship with other transferred constituents.

Ozone observations in the urban atmosphere (at Aspendale) continue and are now being supplemented by measurements made from a light aeroplane, in co-operation with the C.S.I.R.O. Division of Applied Chemistry.

Evidence of the increasing level of ozone in air at Aspendale since 1967 has been deduced by comparison with observations from rural sites in South Eastern Australia, and has been attributed to increased photochemical smog activity. A new

maximum concentration of 12 parts per hundred million by volume was recorded on the 25th February 1972. This is 10% higher than the previous maximum.

Oxides of Nitrogen

Oxides of nitrogen in both the surface air and the upper atmosphere are an important factor in the production and destruction of ozone. Nitric oxide and nitrogen dioxide are generated naturally in the bacterial breakdown of biological material at the surface and by other processes in the upper atmosphere. There are also man-made sources from high temperature combustion processes as occur in automobile and aircraft engines and stationary plant. A programme of instrument development for the measurement of nitrogen oxides in the surface air and the upper atmosphere has now been commenced.

Ammonia

Ammonia is present in the atmosphere as a gas and also in particles of salts which include chlorides and sulphates. These salt particles are believed to be an important source of cloud condensation nuclei.

A theoretical study has been made of the global cycle of ammonia in the atmosphere. Ammonia release and uptake rates were calculated from the governing processes at land and ocean surfaces. These were combined with rates of ammonia transfer in the lower atmosphere calculated from information on momentum heat and water vapour transfer studies completed previously by the Division. The resulting cycle for ammonia is consistent with the limited observational data available. This study provides the basis for designing future observational studies of atmospheric ammonia.

Carbon Monoxide

Measurements of the concentration of carbon monoxide in rain water and in ocean surface waters collected at various locations around the globe, show up to 200 fold supersaturation of carbon monoxide relative to the partial pressure of the

gas in the atmosphere. This supersaturation indicates local carbon monoxide production in the ocean surface waters which appears to represent a major source in the global cycle of carbon monoxide.

A hypothesis has been developed suggesting that the observed carbon monoxide supersaturation in rain water is a product of the photo decomposition of aldehydes by sunlight. A model, based on this hypothesis, successfully predicts the observed daytime supersaturation levels. (The observed night time supersaturation remains unexplained).

This production mechanism may be relevant in explaining the observed carbon monoxide supersaturation in ocean surface waters.

Atmospheric Turbidity

Turbidity studies at Aspendale have continued on a routine basis using pyrheliometric measurements to determine the turbidity coefficient, which defines the fraction of radiation absorbed or scattered by aerosols and particulates.

The results obtained over the period to date have not shown any consistent upward trend in turbidity, as has been observed in some places in the Northern Hemisphere, but the period of observations has not been long enough to allow the formation of a valid conclusion. However, an analysis of the values for global and diffuse radiation from 1961 onwards also shows no indication of a long term rise in turbidity.

Two Volz sun photometers have also been used consistently on cloudless days to measure turbidity. Results will appear in 'Atmospheric Turbidity Data for the World', published by the National Oceanic and Atmospheric Administration U.S.A. Plans for concurrent measurements at Mawson in Antarctica have been shelved due to operational difficulties.

Atmospheric Particulates

Previous reports have referred to the

programme of measurement of the atmospheric particulate loading at Aspendale. This programme has been expanded to include samples from those stations at which atmospheric radioactivity is now monitored. At the time of preparation of the previous report, dust concentrations in surface air at Aspendale had been decreasing over the preceding two years. However, during the last year a consistent increase has been observed and the accompanying figure No. shows levels that are now nearly the same as the maximum recorded in late 1968.

One of the air sampling units and a recording nephelometer have been used to determine the relationship between particulate concentrations and scattering coefficients. A high correlation is found, enabling hourly variations in particulates to be compared with meteorological observations.

The C.S.I.R.O. Division of Applied Chemistry has initiated a programme to study a city as a source of atmospheric pollutants. Atmospheric cross-sections of particulate concentration downwind of Melbourne are being taken by light aircraft, and accompanying their nephelometer on these flights are our own filtering sensors and sensors which monitor carbon dioxide and ozone.

Atmospheric Radioactivity

The Division has organised a national sampling network for Be-7 and is responsible for the analysis of results. The following groups are participating, constituting an effective latitudinal cross-section:-

(a) Physics Department, University of Papua & New Guinea, Port Moresby, T.P.N.G.,

(b) Physics Department, James Cook University, Townsville,

(c) Physics Department, University of Queensland, Brisbane,

(d) Cloud Physics Section, Epping, N.S.W.

(e) The Division of Atmospheric Physics, Aspendale, Vic.,

(f) Physics Department, the University of Tasmania, Hobart.

Gamma spectrometry is used to measure the quantities of naturally-occurring Be-7 (which is largely of polar stratospheric origin) and the fission products Cs-137, Ce-144 and Nb-Zr-95 on each filter. Since initiation of the project in August, 1971, the 1971 testing of atomic weapons in French Polynesia has resulted in concentrations of short-lived radioactive products sufficient to interfere with our basic measurements. It is hoped that levels of radioactivity will remain low in the next few years so that the times and latitudes of seasonal increases in airborne radioactivity can be properly identified.

The Division has been monitoring the radio-activity deposited in rain at Aspendale since 1958. These measurements are continuing but no unusual changes have been noted in the past year.

VI UPPER ATMOSPHERE

The studies of ozone in the past concentrated mainly on understanding the general circulation of the stratosphere using ozone as a tracer. With the possibility of supersonic transports flying in the near future in the stratosphere, the study of ozone has assumed a note of urgency in terms of the attendant pollution problems. Twin problems concern the photochemical effect of the exhaust gases on ozone formation or destruction, and the consequential re-distribution of ozone due to transport processes in the stratosphere. Present theoretical treatments of the photochemical processes are believed to be seriously inaccurate and it appears that much greater concentrated effort in the observational programme is now needed.

In the Australian region the observational programmes at six stations, Darwin, Brisbane, Aspendale, Hobart, Perth and Macquarie Island have

continued. Apart from Aspendale, the observations are made by the Bureau of Meteorology with the Division responsible for oversight of standards and training, and for analysis. Standards are maintained by inter comparison of Dobson Spectrophotometers measuring total ozone content and vertical Distribution through the atmosphere. All stations are equipped with these instruments. Recently a regional comparison of Dobson Spectrophotometers in the W.M.O. region $\overline{V}$ (the S.W. Pacific), was undertaken under the auspicies of the World Meteorological Organisation. The U.S. standard Dobson Spectrophotometer used to compare other spectrophotometers in the U.S.A., was brought from Boulder (Colorado) and was compared with its counterpart at Aspendale. Recalibrations were done by simultaneous observation and it was found that the difference in ozone values obtained by the two instruments was less than 3% of total ozone. Such a comparison between New Zealand and Aspendale instruments had already been made. Thus we now have a sound basis for strict intercomparability of results throughout the S.W. Pacific and North American regions. Similar intercomparisons linking with the Asian network are under discussion.

As reported earlier, it was noticed that in the last decade, there has been a small upward trend in total ozone recorded at Darwin and Brisbane, and a lesser, doubtfully significant change at Aspendale and Macquarie Island. In the same period the 100 mb temperatures in Brisbane and Aspendale and Hobart have been rising, implying the strengthening of the transport processes in the lower stratosphere in these latitudes.

Using the last ten years' observations from Brisbane and Aspendale, an attempt was made to find out how much of the calculated increase in ozone could be explained by an increase in total dust and particulate concentration. It appeared that at least half of the increase could be accounted for in this way.

Routine weekly soundings of the vertical distribution of ozone using Mast-Brewer ozone sensors have been continued. These have now been

made routinely for seven years, providing the longest continuous climatological sample of direct ozone soundings in the world. In view of the growing interest in atmospheric monitoring, particularly stratospheric ozone, this data provides a unique and valuable base-line climatological series.

A meeting of the working group on ozone for Region V of the W.M.O. was held in Aspendale early in 1972. The countries represented were Australia, New Zealand, Phillipines and the U.S.A. A representative of the Secretary General of the W.M.O. was also present. The group made a number of recommendations aimed at improving the network of ozone stations in this region. The meeting was extremely successful. Dr. Kulkarni is the member representing Australia on the working group. A report of the meeting will appear in the W.M.O. Bulletin.

Current studies and observations of near surface ozone, other atmospheric constituents and pollutants, are discussed under the heading 'Quality of the Environment' on page 21.

Airglow

Understanding of the stratospheric circulation will be enhanced if we know the interaction between the stratosphere and the upper atmosphere, at about 100 km. The dynamics of the upper atmosphere can be studied to some extent by the relatively straightforward technique of ground-based airglow measurements. The observations of radiation intensity already made on λ5577 on the night sky have given interesting results relating the transports at 100 km to winds lower down. These however, cannot be confirmed for lack of detailed data. The airglow equipment has now been improved by a yoke mounting which enables the instrument to track automatically from north to south and east to west once every thirty minutes - provided the sky is sufficiently free of cloud for the observation to be useful.

Work on atmospheric radioactivity is listed under 'Quality of the Environment' on page 21.

VII AGRICULTURAL METEOROLOGY

The exchange of heat, water vapour and carbon dioxide between the atmosphere and vegetated surfaces, particularly as related to crop evaporation and growth, continue as the main concern of the agricultural meteorology group.

Interests are wide-ranging, for example, from wind-tunnel considerations of models of individual leaves to continuous weighing of 6 ton soil and plant containers to monitor crop water relations.

The group has played an active part in the Rutherglen project, and apart from the data acquisition itself there has been much preparation of data for subsequent analysis. The magnitude of this last can be gauged from the fact that 39 of the measured variables were recorded hourly, 24 hours a day for most of the 7-month experimental period.

Numerical Models of Trees

One of the questions of interest is the extent to which the atmospheric environment has determined (on the time scale of evolution) the gross morphology of plants and animals. Allied to this is the question - "Given a particular environment, what would be the optimum morphology of a plant (say) if it were to perform such and such a function? (Maximise its rate of photo-synthesis for instance)." One of the methods of answering such questions is to develop much simplified analytical models of the particular organism - the art being to simplify to the extent that the mathematics are tractable, but still to retain the essential features important to the organism as far as its performance of the required function is concerned.

This technique has been applied to the study of the gross morphology of trees - both isolated trees and trees in a forest. Expressions have been derived which relate their rate of growth to environmental conditions (e.g. solar elevation, potential evaporation, soil moisture status and so

on) and to their gross morphology (size, shape, distance apart, and leaf density distribution). These expressions have been used to predict, for instance, the optimum spacing of trees to achieve maximum rate of growth at any stage, or the maximum rate averaged over the tree lifetime, and to predict the optimum shape of the trees in a forest at each of the various stages of growth, again in order to maximise their rate of growth. In the broad manner of this sort of modelling, the predicted spacings and shapes of the theoretical trees appear very similar to those found in the real world.

Carbon-Dioxide Exchange Over a Wheat Crop

The following results were obtained from the calibrated infra-red gas analyser installed at Rutherglen, N.E. Victoria, to measure vertical gradients of CO_2 (ΔC) above the experimental wheat crop. Sampling was effected at three locations in the field at heights of 1 m and 2 m above the crop, by passing air from the six field intakes sequentially through the analyser, and comparing the concentration to that with air drawn from a selected (reference) intake. Each cyle of six comparisons lasted six minutes. Hourly mean 2 m - 1 m differences throughout the growing season have been tabulated.

Vertical fluxes of CO_2 aave been determined from the mean vertical gradients of CO_2, horizontal wind speed at 2 m and 1 m (U_2 and U_1 respectively) and the temperature difference between 2 m and 1 m, ($\Delta\theta$) using the relation

$$\text{Flux} = \text{constant} \times f[(u_2 - u_1), \Delta\theta]\Delta C.$$

They were used to evaluate the crop growth on a daily basis, and showed good agreement with direct measurements of daily crop growth found by weighing plant samples.

In well developed nocturnal inversions, ΔC has been found to execute regular oscillations in amplitude, of period 2-4 hours, correlated with the variation in local Richardson number - the latter

indicating periods of fully turbulent flow interspersed with periods of quiet flow. During the quiet periods, ΔC can attain values of 20-30 ppm, an order of magnitude or more greater than those in the daytime. The oscillations may result from the action of two opposing forces acting on the stable air layer - the large scale horizontal pressure gradient tending to accelerate the air and the surface friction tending to decelerate it. An additional oscillation in ΔC, of smaller amplitude and period (1 hour), has also been observed in nocturnal inversions, and may be due to the presence of internal gravity waves.

Microclimate in Relation to Individual Leaves and Plants

Work is expanding on the relation of plant geometry and function to microclimatic factors. These ecological studies aim to increase understanding of the adaptation of wild plant species to their native environments. Such work has an immediate practical application in modelling crop growth and in the re-design of plant varieties by plant breeders.

Also contributing is the study of convective heat transfer from models of single leaves. Fluctuations of velocity appear to resonate with the frequency of vortex shedding from the rear of tilted plates. This process can increase the heat transfer by 50% or more above steady state levels.

A mathematical model of mass transfer from leaves indicates that hypostomatous leaves (pores on only one side) may have water-use efficiencies up to 50% higher than amphistomatous leaves. This has probably affected natural selection for the two types of leaves in various environments, and is an example of a result which may be useful to plant breeders.

A related model is being developed to investigate the coupling among water uptake, water loss, and stomatal opening. Two parameters receiving special attention are the minimum stomatal resistance and the rate constant relating

resistance changes to water potential changes.

Two unusual plant forms are being studied as special cases. One is the cushion growth form, common in the world's arctic and alpine regions, the shape apparently helping to conserve heat. Field measurements of convective heat transfer from real and model cushions have begun. "Compass" plants, especially some members of the sunflower family, sometimes align their leaves quite strikingly north and south. Calculations are underway to determine in what way this alignment is advantageous to the plants.

Evaporation - Estimation and Measurement

Extension workers and others concerned with evaporation from natural surfaces have often successfully estimated evaporation under conditions of plentiful water supply to so-called "potential evaporation". Estimation under drier conditions (or appropriate modification of the estimated potential value) is much more difficult.

A recent modification of a "combination-type" formula permits empirical allowance for the moisture status of the evaporating surfaces. The complexity (and accompanying accuracy) of the estimate may be varied in accordance with the meteorological and other information available - from detailed, accurate data to simple, even subjective, assessment of components of the evaporative conditions.

Various aspects of stomatal control of evaporation and their practical significance have recently been debated in the literature. Considerable departures from potential evaporation rates, and accompanying symptoms of plant moisture stress, have been observed under conditions of apparently generous soil water supply. They occurred on days of high potential rates, being as much as 20% below evaporation levels which might otherwise have been expected. Effects were greater with potato crops than with pasture, and with clover-dominant pasture, than with grass-dominant pasture. However, in terms of seasonal or annual evaporation the reductions amount to only a few per cent.

Instrumentation

One of the services the Division provides for industry is the calibration of ground heat flux plates. The equipment used for the work has, until recently, been of an early design necessitating working in a controlled environment. Re-designed equipment overcomes this problem and as well is much easier and quicker to operate.

Over the wheat crop at Rutherglen this year temperature gradient measurements are being made using a new mast which has motorised rotation, elevation and instrument changeover.

Lysimetry: The special balance for measuring evaporation from a snow surface has been re-designed in the light of experience gained in previous seasons. It is to be re-installed at Falls Creek, Victoria, for further testing and operation. Developmental work has also proceeded on the simple, low cost, cable-pivot lysimeter balance, mentioned in previous reports.

Combination Atmometer: The combination atmometer has been designed as a simple straightforward device to provide a good 'first estimate' of potential evaporation in areas where sophisticated instrumentation is not available.

It consists basically of two small water containers mounted alongside each other, one carrying an opaque sunshield, the other a dimensionally similar but transparent shield. Weight variations resulting from evaporation are combined in two different ways to give, on the one hand, a measure of potential evaporation, on the other, a measure of net radiation.

During the past year, new units were designed which were less bulky than the original and approximated more closely the simple mathematical model on which the method was founded. Other work has modified the system in an attempt to estimate actual potential evaporation. For this purpose, a third water container, carrying an opaque shield has

been mounted above the other two containers.

VIII CLOUD PHYSICS SECTION

This section is concerned with the general question of weather modification either through a deliberate intent or through inadvertence. For many years a major part of its activities has centered round cloud seeding which is carried out with the intention of increasing precipitation both from single clouds and over an area of the order of a thousand square miles. Improvements have been made in experimental design, seeding techniques and methods of analysis and much research effort has been devoted to an understanding of the microphysical aspects of seeding. More recently interest has spread to an examination of scales larger than the microphysical, to cloud scale processes and to the possibility that areas well outside the target area have been affected by seeding experiments.

From research into the variety of sub microscopic particles which act as nuclei for condensation or freezing in natural clouds and which are of importance in precipitation processes, whether natural or artificial, has grown an interest in how alterations in the concentration of particulates through man's activities may affect the earth's weather.

Cloud Seeding Activities

The Section has recently completed an area-seeding experiment in Tasmania the analysis of which is still proceeding. A preliminary analysis, recently confirmed by different techniques used by officers of the Division of Mathematical Statistics, has indicated that in Autumn and Winter seeding resulted in precipitation increases of nearly 20%; the probability of a result as large as this or larger being due to chance is assessed at being less than 3%. The results are currently under detailed investigation by both Divisions to learn more about the circumstances under which seeding was effective. A second four year experiment was started in 1971 by the Hydroelectric Commission of Tasmania but was

suspended late in the year because of financial problems and because the storage reservoirs were full. It is hoped that this experiment will recommence at a later date.

As a prelude to the initiation of further area seeding experiments other areas of Australia in which seeding may be beneficial are being explored. A study is being made of an agricultural and irrigation area near Emerald, inland from Mackay, Queensland. Three short expeditions were made there during the past summer and individual clouds were seeded in various ways. First impressions were that clouds suitable for seeding occurred with reasonable frequency. If further seeding experiments confirm that clouds in this area can be stimulated to produce more rain it is intended to commence a four or more year experiment probably starting in 1974.

Ice Nuclei and Ice Crystals

Since present seeding techniques depend for their effectiveness on supplementing natural ice nuclei with artificial nuclei such as silver iodide, a large part of the Section's research effort has always been devoted to a study of the nature and mode of action of such nuclei and into the way in which ice crystals form in clouds. It is generally assumed that these nuclei originate solely from the earth's surface, being soil particles swept up by the winds. Previous work in this Section, involving comparisons in the concentrations of nuclei in maritime and inland situations, high and low latitudes or in Australia and the Antarctic, has suggested alternative origins. This year has seen the completion of a 3 year programme of measurement of the concentration of ice nuclei in remote oceanic areas from the research ship US Eltanin or its almost continuous voyages from latitude 20°S to 78°S and 90°W to 90°E longitude centred on Australia. The highest concentrations of nuclei occurred near latitude 40°S at all longitudes, with no evidence for a down-wind plume from Australia. This is the latitude band at which stratospheric-tropospheric air interchanges most commonly occur. From this and

other evidence it is thought that the source of many of the ice nuclei is in the stratosphere.

One of the major current problems facing the Section is that certain clouds appear capable of producing large numbers of ice crystals naturally when laboratory or field measurements indicate that only small numbers of ice nuclei are present. Aircraft observations in natural clouds indicate that this apparent "multiplication" process is associated with the presence of a wide size distribution of cloud droplets but a great deal of laboratory work has so far failed to discover the physical mechanism involved. Numerical modelling experiments of the glaciation process whereby ice crystals collect or are collected by supercooled water droplets thus inducing freezing also point to the importance of a wide cloud droplet size distribution.

Condensation Nuclei and Water Droplet Size Distribution

It has long been recognized that the ease with which a cloud produces rain, depends heavily on the size distribution of the droplets which first form. This in turn depends on the condensation nucleus size distribution and on the updraft velocity or rate of cooling. In addition to its effect upon precipitation processes cloud microstructure also influences the optical properties (notably the short wave albedo) of clouds. To establish a reasonable climatology for the cloud condensation nuclei, and to give a bench mark record for examining any secular trend in particle concentration, an automatic program of hourly observations has been in progress at Robertson N.S.W. since mid-1968. This uses a thermal diffusion cloud chamber producing supersaturations similar to those which occur in natural clouds. The results in conditions of steady wind show a consistent diurnal pattern in the concentration of cloud nuclei with a maximum in the evening and a minimum in the early morning.

While the observed concentration of droplets in natural clouds can be accounted for quite closely

on the basis of observed cloud nucleus spectrum and updraft velocity certain aspects of their size distribution are not as well understood. Recent theoretical work suggests that while mixing between cloud and clear air environment changes the bulk properties of the cloud it is not a dominant process in determining the droplet size distribution.

Convection and Mixing Processes

All clouds mix to a greater or lesser degree with their environment. This provides a brake on their growth through reducing their buoyancy. Measurements from aircraft of the turbulent velocities in clouds are important for the light they may throw on the nature of this mixing process. In addition to measurements of updraft structure in clouds, observations are made of the fine scale fluctuations of velocity, temperature and moisture content in the clear air between the surface and cloud base in order to calculate the upward fluxes of heat and vapour. The analysis of such a study made in trade wind conditions seawards off Cairns, Queensland, has just been completed.

Stratospheric Particles

Results obtained by the Section suggesting that some of the ice nuclei were of stratospheric origin led to an investigation of the nature of the particles in that region and over the past four years methods of collection and examination of particles captured from balloons have been developed. Specimens are collected by impaction on electronic microscope screens as the carrying balloon passes the desired level; they are recovered after the scientific payload parachutes to earth at the end of the flight. During the past few years widespread concern over possible influences on the atmosphere of regular commercial aircraft flights at high altitudes has caused this work to take on more than a cloud-microphysical significance. It has reached an interesting stage during the past year since not only can the mass and number concentration of particles be estimated as a function of height but some idea can now be obtained of the chemical composition of

individual particles whose weight may be only 10^{-15} gm. The technique involves precoating the surface of the electron microscope screen used for collection with a thin film of reagent by vacuum deposition. After the specimen has been collected the screen is exposed to an atmosphere saturated with water vapour, alcohol vapour or other reaction medium for a suitable time; it is then dessicated and shadowed with a metal to give contrast and examined in the electron microscope. [Examples are shown in the accompanying figure of typical small particles collected at an altitude of 20 km on a non-reactive carbon film (left) a copper film (centre), and a barium chloride film (right). Their reaction with copper shows that they contain either nitric or sulphuric acid, while their reaction with barium chloride narrows this down to sulphuric acid. Since sulphuric acid is liquid at room temperature and the particles on the carbon film are obviously at least partially solid it is clear that some cation must also be present. The almost complete reaction with copper suggests that this must be ammonium which alone forms a complex salt with copper sulphate.] This work appears to offer considerable promise for the future not only in stratospheric studies but also in those of urban pollution where, with suitable collection methods, the same chemical techniques can be used for particle identification.

IX COMMONWEALTH METEOROLOGY RESEARCH CENTRE

The Commonwealth Meteorology Research Centre in Melbourne is a joint venture between the Commonwealth Bureau of Meteorology and this Division. The objectives of the Centre are set out in previous annual reports. Its own annual report is published separately.

X MISCELLANEOUS

Forest Fires

In last year's report, mention was made of an expedition in collaboration with the C.S.I.R.O.

Division of Applied Chemistry to investigate smoke from deliberately-lit forest fires in W. Australia late in 1970. The results of this series of observations have now been worked out and, though much of the work was concerned with the composition of the gases and particulate matter, results of meteorological interest were obtained. A considerable amount of flying through the smoke plumes from these fires confirmed our previous experience that the associated turbulence is far from intense and cannot be regarded as a hazard to aircraft. On the other hand, the extent of the plumes and the consequent reduction in visibility over large areas can cause considerable difficulty in aircraft naviation.

A typical plume could be followed as an entity for distances of some 60 km with a maximum width of up to 10 km; isolated patches of smoke outside these limits were also observed. Crosswind turbulent diffusion coefficients of the order of 10^7 cm^2 sec^{-1} were measured, in agreement with earlier large-scale diffusion experiments; the angle of lateral spread of the plumes was consistently close to 12½° for wind speeds varying between 7 and 15 ms^{-1}.

An opportunity to complement the work reported last year was provided by another intense fire in the spring of 1971. It resulted from the decision by the Northern Territories Works Department to clear vegetation from the site of a new dam (near Darwin) by burning.

The usual technique of ignition from the air was followed and the entire area of some 10,000 acres was largely burnt out in about three hours. Convection rose to almost 5,800 m. Although analysis of the results is incomplete it would appear that the rate of entrainment of ambient air into the smoke column was less than in the case of the three intense fires studied in 1969. This effect appears to be connected with the much greater rate of burning encountered this time.

Bushfire Observations

A bushfire outbreak in the Dandenong Ranges,

(30 m north-east of Melbourne) in 1968 has been studied in terms of photographic records and radar observations. This information was supplemented by data on wind and temperature supplied by the Bureau of Meteorology, positions of fires supplied by the Country Fire Authority and fuel burning rates supplied by the C.S.I.R.O. Division of Applied Chemistry.

From the data available, the rate of spread of the smoke, both upwards and horizontally, was measured. The vertical velocity of the transient cumulus turrets rising above the smoke plume was estimated, average maximum being 6 m sec^{-1} at 2 km. Horizontal velocities were also estimated, and these accorded well with those measured by the Bureau of Meteorology, while the height of the plume agreed broadly with the deductions from the observed temperature profile.

Calibrations

N.A.T.A. (National Association of Testing Authorities) is an organisation established to maintain and improve standards of testing and calibration within Australia. The actual work is carried out in suitably equipped and approved laboratories (both government and private) selected by the Association. This Division is one such laboratory in the fields of low-speed anemometry and atmospheric and terrestrial radiation instruments. The number of anemometers received for calibration continues to rise steadily and this year reached 276. The number of radiometers remains steady at about 350 p.a.

Computing Aids

Extensions to the analogue-digital data conversion system which was built in the Division have been completed and the system is now in operation. The equipment is currently being used to process data from the Hay convection experiment.

The Division recently acquired a small computer (Hewlett-Packard 2100A with 8000 words of

memory) which is intended for use as a data logger and processer, both in the laboratory and on field expeditions.

A Teleprinter link with the Organisation's CDC 3600 computer was installed in the Division this year, and has led to a marked improvement in the turn around times involved in programme testing.

XI ACTIVITIES AND PERSONALIA

Activities and Overseas Visits

In July 1971 the Chief of Division, Dr. C.H.B. Priestley left for Moscow to attend the General Assembly of the UGGI, as the leader of the Australian delegation. He presented the invitation for Melbourne to be the venue for the 1974 First Special Assembly of the International Association of Meteorology and Atmospheric Physics. The voting (Melbourne, Munich) was tied and the President's casting vote was in favour of Melbourne.

At the General Assembly of IAMAP (Moscow), the following members of the Division were elected to office.

C.H.B. Priestley	First Vice-President of IAMAP
E.K. Bigg	Commission on the Meteorology of the Upper Atmosphere
A.J. Dyer	Commission on Atmospheric Chemistry and Global Pollution
R.N. Kulkarni	Ozone Commission
S.C. Mossop	Commission on Cloud Physics
C.H.B. Priestley	Joint Committee on Air-Sea Interaction.

In September 1971 the Australian Academy of Science set up a working group to report on the atmospheric effects of supersonic aircraft. The group was chaired by the Chief and included Dr. E.K. Bigg of the Cloud Physics Section and Mr. B.G. Hunt of C.M.R.C. The report was published

in February 1972.

CSIRO, in association with the Australian Academy of Science and the American Meteorological Society sponsored an International Conference on Weather Modification, in Canberra from September 6-11 1971. This was organized by members of the Cloud Physics Section and the Division of Radiophysics and attended by 120 delegates, some 50 of whom were from overseas.

During October 1971, Dr. A.J. Dyer visited Japan to attend a planning conference for AMTEX - a Japanese experiment in 1974 over the Sea of Japan - forming a sub-programme of the larger world-wide GARP programme. Dr. Dyer is the Australian representative on the Steering Committee, which comprises also representatives from Canada, U.S.A. and U.S.S.R. He broke his journey to call briefly at the University of Papua New Guinea in Port Moresby.

Dr. S. Twomey participated in a Study of Man's Impact on Climate held in Stockholm Sweden between June 28th and July 16th 1971. He also attended a Study Group Conference on Parameterization of Sub-Grid Scale Processes in Leningrad between 20th and 27th March 1972.

Dr. F. A. Berson commenced 9 months leave of absence from the Division in May 1972: he is attached to the National Hail Research Experiment, NOAA Boulder, Colorado.

In May 1972 Dr. G. W. Paltridge attended the International Radiation Symposium at Sendai, Japan. Advantage was taken of the trip to visit the Japanese Meteorological Agency and Meteorological Research Centre, and the Royal Observatory, Hong Kong.

Nominated the official Australian delegate, Mr. I. C. McIlroy was overseas in May 1972 to attend the 8th International Commission on Irrigation and Drainage Congress in Varna, Bulgaria.

Visitors from Overseas

Dr. C.G. Little, Director of the Wave Propagation Laboratory NOAA Boulder, Colorado, completed an 8 months sabbatical in August 1971. He was concerned with remote probing of the atmosphere using electromagnetic and acoustic techniques.

From the Central Meteorological Office in Korea Mr. Hyeongjin Son is spending 12 months with the Division under the Colombo Plan Scheme. Mr. Son works in the field of meso-meteorology with particular reference to the development of thunderstorms.

In January 1972 Mr. Fumihiko Fujimoto returned to the Aerological Observatory, Tarten, Japan, having spent 5 months in the Division working on the relationship between atmospheric turbidity and incoming radiation.

Dr. W. R. Cotton of N.O.A.A. Experimental Meteorology Laboratory, Coral Gables, Florida, visited the Cloud Physics Section for a period of four months commencing on 29th March. His main interests lie in numerical modelling of cumulus convection.

Dr. A. Long, a recent graduate of the University of Arizona, took up a National Science Foundation Fellowship on 6th June and will be working with the Cloud Physics Section for a twelve month period.

Dr. P. G. Baines, holder of a Queen's Fellowship will be with the Division for 2 years. His field is the dynamics of internal waves.

Continuing the pattern set in recent years, the Division has again received requests from overseas to train Colombo Plan Fellows or others sponsored by the U.N. or its specialised agencies such as the WMO.

Mr. Gaudioso Tabamo, a senior meteorologist from the Philippines Weather Bureau, completed a

3 months attachment to the Division in May 1972. Agro-meteorology was his particular concern.

With similar interests is Mr. J. Rodjali from the Indonesian Meteorological and Geophysics Service. A WMO Fellow, he will be attached to the Agro-meteorological group for some 12 months.

New Appointments

Dr. A.J. Dyer, who has been in the Division since 1954 was appointed Assistant Chief in August 1971.

Dr. K.T. Spillane, formerly with the Commonwealth Bureau of Meteorology, joined the Division in November 1971. He works with the Dynamic Meteorology group and is concerned particularly with the movement of material on the sea surface.

In January 1972 Dr. R.N. Robinson, from the University of Western Australia, took up a 3 year Fellowship. He works with the Dynamic and Synoptic Group.

Resignation

After nearly 24 years with the Division, Mr. W.C. Swinbank FAA resigned from C.S.I.R.O. in August 1971. He joined the Division early in 1948, just over a year after its inception. Well known for his pioneering work in micrometeorology, Mr. Swinbank contributed to the development of the Division on the widest front, making many innovations in its structure and programme. Aside from his area of specialisation he supervised, at different times, the work on radiation, on agricultural meteorology, and the introduction of the ozone programme. The Division is greatly indebted to his work, and all wish him success as Director of the National Hail Research Experiment in the U.S.A.

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XIII STAFF

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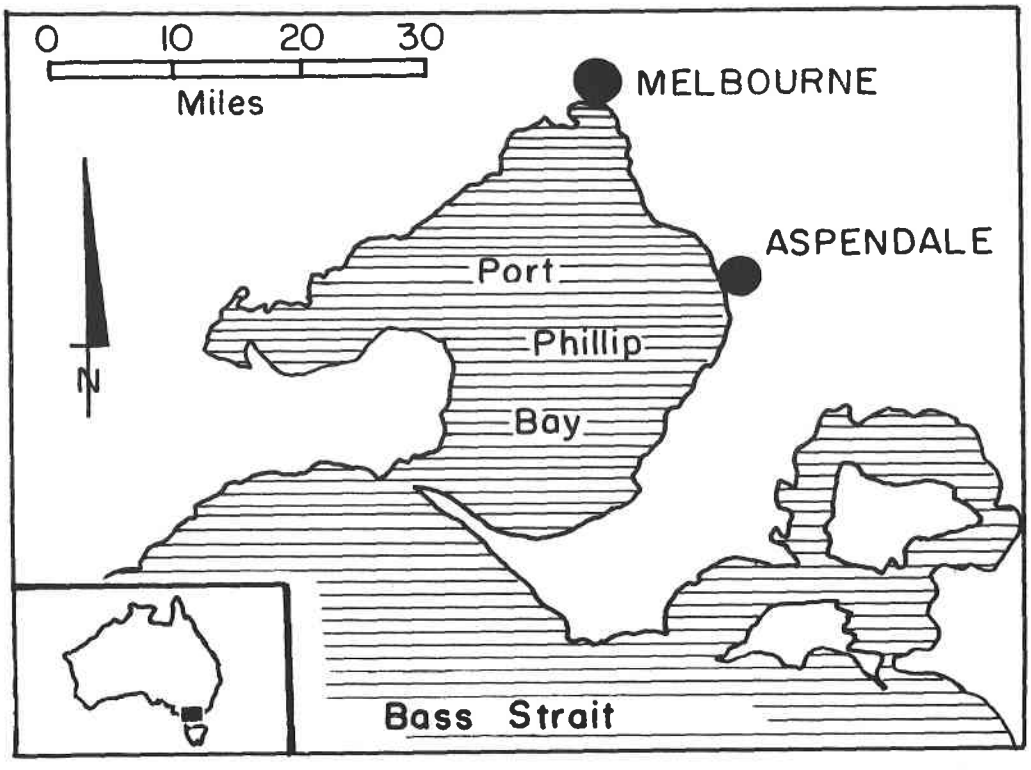
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