BIENNIAL REPORT 1975-77

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COVER PICTURE:

The proposed site for an Australian Baseline Air Pollution station, Cape Grim, N.W. Tasmania.

I. INTRODUCTION

The atmosphere exerts a major influence on numerous aspects of life. Associated problems are many and varied but central to all are 'weather' and 'climate', acting on regional, continental and global scales. The overall objective of the Division of Atmospheric Physics is to determine the characteristics of and the processes within the atmosphere and its interactions with land and sea surfaces in order to provide an improved understanding of weather, climate, and atmospheric phenomena generally that might provide the scientific basis for better predictions of weather and climate and for the more efficient control of pollution. The method of attack involves a combination of techniques including field observations, empirical data analysis, laboratory and numerical modelling, and analytical theory.

Anticipating and reacting to social factors, progressive changes have taken place in the direction of some programmes. Research activities in climate and atmospheric chemistry are examples of anticipation; burgeoning urban pollution research is an example of reaction. The Division takes some pride in the particular relevance of its research programme to emerging topics of environmental concern: factors affecting the ozone protective layer and ultra-violet radiation at the surface, global pollution (particularly carbon dioxide), local environmental characteristics affecting industrial siting, and possible climate variation, to mention only a few. Indeed this relevance itself creates a problem in some areas because of the need to maintain the momentum of progressive research in the face of increasing requests for consultative advice.

One of the most pervading changes in social concept over the last twenty years has been the emerging awareness of the finite nature of the earth-atmosphere-ocean system in which we live and the precious nature of the environment. In the wake of this have come many apprehensions not the least of which concerns the stability of climate and, in particular, what effect man's activities might have on it. The strain imposed on world food production by growing population increases the possible impact of even minor climatic variations. The range of possible research topics on climate and possible climate forecasting is enormous. At one extreme is the substantial analysis of past data and projection into the future using various assumptions of repetition. At the other are the all-embracing numerical models of weather producing systems in the global atmosphere which attempt a complete mathematical description of the significant physical processes: this approach to climate study involves time integration into the future on an hour by hour basis. In between are a large variety of possible approaches involving empirical studies, different forms of relatively simple models and, by paying attention to broad controls, the isolation of cause and effect. The developing climatology research programme in the Division focuses on this middle ground.

One of the basic stumbling blocks in all quantitive studies of weather and climate is the obvious impossibility of describing and forecasting every process and motion in the atmosphere in complete detail. Large-scale processes must be described fairly explicitly in any quantitive synthesis but smaller-scale processes which often have a fundamentally important cumulative effect must be represented in some other way — often implicitly by describing their effects in terms of the explicitly represented larger scales. This can be achieved satisfactorily only by understanding the physical basis of these processes. Thus, in a sense, virtually all the research in the Division is necessary for a wider understanding of climate.

II. RADIATION — SOLAR AND THERMAL

The physical basis of climate is dominated by the energy input and output of the earth-ocean-atmosphere system, that is, by the net solar energy stream into the system and the infra-red stream back to space. In turn, a prime control on these radiation streams is the amount, type and distribution of cloud around the world. Thus, if climate forecasting on a physical basis is to be possible, it will be necessary to understand the effect of cloud on the radiative input and output and the processes which create and maintain the cloud, many of which processes are themselves radiatively controlled.

Studies within the radiation programme are both theoretical and experimental. The theoretical side is concerned with the 'parameterization problem' — the incorporation of suitably averaged cloud-radiation processes, surface albedo, etc. in climate models. The experimental side includes in situ measurements to examine the relation between radiation and cloud character. It is particularly concerned with remote sensing of the radiative properties of clouds using lidar and narrow beam infra-red radiometers. This aspect of the work is related to several others, including the monitoring of (a) aerosols, which are a form of cloud as far as radiation is concerned and which may be a factor contributing to climate change; (b) certain surface characteristics relevant to climate studies (albedo, soil moisture, etc.), and (c) certain atmospheric characteristics such as turbidity (aerosol content) and ultra-violet radiation intensity (the latter related to stratospheric ozone and the "skin cancer" problem).

Future climate studies and weather forecasting will be increasingly dependent on satellite data. The radiation programme therefore includes ground-based and airborne studies of the potential of remote sensing of the earth-ocean-atmosphere system from earth satellites.

The calibration and standards laboratory forms an important basis for much of the experimental research but itself depends largely on the research for impetus and quality. The laboratory has a role as an international observatory of radiation quantities (see Section IX) and in this respect is also closely linked with the remote sensing aspect of the programme.

Radiative Properties of Clouds

(a) Stratocumulus

For a number of years the Division has been pursuing experimental research into the radiative interaction of these low level clouds in conjunction with the Division of Cloud Physics. The latest expedition was to Hobart in May, 1976, and was perhaps the most successful of the series in that all systems operated well during the experiments on a number of almost ideal case studies. One of the most important results to emerge from the series (and which has been checked theoretically) is that drop-size distribution within these water clouds is not really significant to the radiative interaction. This is enormously important for climate modellers as it would be almost impossible to handle the detail of drop-size distribution within clouds.

(b) Upper level cloud

The success of the programme on stratocumulus has led to a gradual switch of emphasis to upper level cloud — a more difficult problem both theoretically (because of ice particles) and experimentally (because they are too high for normal aircraft experiments). As a result increased use is being made of remote sensing techniques utilising for example, Lidar, and the various infrared radiometers developed in the Division. The work at present is still exploratory as the problem of cirrus and altostratus parameterization has yet to be adequately defined, except in broad terms. Nevertheless the work is gradually becoming coherent, and furthermore is spilling over into a number of related areas including tropospheric and stratospheric aerosols (another type of 'cloud' as far as climate is concerned) and satellite remote sensing of upper level cloud.

(c) Lidar studies

These include:

(i) The sounding of middle-level mixed-phase clouds, the identification of separate layers of water and ice, and the preliminary identification of layers of hexagonal ice crystals which are apparently orientated with their long axes in the horizontal. Those layers give characteristic angular backscatter and depolarization signatures, which aid in their identification.

(ii) A study of a series of widespread, dense cirrostratus cloud systems in terms of their infrared emissivity and gross characteristics, such as internal structure, cell structure, etc. These systems are often 3 to 4 km in depth but the average emissivity of many samples is only of the order of 0.5.

(iii) Multiple scattering in the lidar return from dense clouds is being measured and compared with theoretical Monte Carlo computations employing a variety of theoretical ice scattering patterns. The object is a better understanding and measurement of the multiple scattering component and thus an improved measurement of the single-scattering, optical depth of the cloud— needed to specify the cloud solar albedo. Quite good agreement between experiment and theory is being obtained, at least for some phase functions.

(iv) An experiment to measure the differential absorption in atmospheric oxygen aimed at trying to specify the atmospheric pressure and temperature profile. Conceptually this was a joint effort with Dr. W. L. Smith from NOAA who was temporarily attached to the Division (see Section IX). An essential aspect of the work involves shifting the Lidar's wavelength to the oxygen absorption band at about 7600Å using stimulated Raman scattering. This is the first known application of this technique to laser sounding.

(v) A program to compare lidar and satellite infrared soundings, again in collaboration with Dr. Smith. The object was to improve satellite temperature retrievals from passive radiometric data by specifying the atmospheric temperature inversions from lidar measurements of aerosol. The program also included the comparison of cloud top heights from lidar measurements with those calculated from passive radiometric measurements. Quite good correlations were obtained.

Satellite Energy Budget Analysis

Looked at from an overall stand point, one of the most basic questions about the world's climate is the degree to which the global system departs from its steady state. This question has been examined in terms of the total solar input and the total infrared output from the planet — radiant energy fluxes which are controlled primarily by cloud amount. We know for instance that on average 50% of the earth's surface is covered by cloud, but we know nothing about the variability of this amount (or the associated radiative input and output) on the scale of days to weeks.

Six months of the GOES 1 satellite imagery have been examined to provide a first order answer to this question. It appears that the variability of the entire planet is somewhat less than 5% on this time scale. A further interesting fact to emerge from the study is that the variability within that small percentage appears to have a distinct 8 day cycle — with evidence of a further 20 day cycle showing up in mid-latitudes in the northern hemisphere winter. This last cycle has appeared previously in numerical modelling experiments of the ANMRC among others, so is not completely unexpected.

Solar Aureole Studies

Measurements of radiation scattered by atmospheric aerosols at angles close to the solar disc are being used to characterise the aerosol extinction and size distribution. Preliminary results with a new instrument indicate quite different scattering patterns for visually 'clear' days and days of visually dense haze.

Ultra-violet Radiation Monitoring Network

The network of monitors of 'erythemal ultra-violet' (290 — 320 nm) has been expanded to include Darwin, Hobart and the new Australian Baseline Air Pollution Station at Cape Grim, north-west Tasmania. The network of 7 monitors now provides adequate latitude coverage from Port Moresby (9°S) to Hobart (43°S) and is complementary to similar networks overseas. However, in terms of cosine response and ability to monitor UV in quantitative physical units, the instruments are superior to those commonly used elsewhere.

The analysis of some two years' continuous data is proceeding in parallel with theoretical work aimed at predicting ultra-violet intensities. A number of discrepancies between theory and measurement remain to be resolved. The work is currently of considerable importance in at least two contexts; that of the plastics and paint industries and the degradation of materials by UV radiation, and intrinsically, inasmuch as the results bear directly on the 'ozone problem' met with in climate modelling.

It is hoped in the near future to hand over more of the pure monitoring aspects to other organizations.

Standards, Radiometer Calibration and Observatory

Standards

In October 1976, the fourth International Pyrheliometric Comparisons of the W.M.O. took place at the World Radiation Centre, Davos, Switzerland. Two of the Division's standard instruments, Angstrom pyrheliometer No. 578 and Active Cavity radiometer No. 701 took part in these comparisons, representing the Region V Regional Standard. The measurements made at Davos confirmed the discrepancies observed elsewhere in the International Pyrheliometric Scale 1956, and as a result it is anticipated that a new scale, to be known as the World Radiometric Reference will be introduced later this year.

Calibration

As an additional facility for calibrating radiometers a large (2 m diameter) integrating sphere is at present under construction in the Division's workshops. This will enable radiometers to be calibrated under an effectively isotropic hemispheric source of radiation.

Observatory

The rebuilding of the spectral pyranometer to operate in the ultra-violet waveband (290—490 nm) has been completed and some experimental results obtained. The wavelength scale is self-calibrating by observing the major Fraunhofer lines, clearly. distinguishable in the trace.

Co-operation

As a co-operative project with the Darling Downs Institute of Advanced Education, global and diffuse radiation as well as some other meteorological parameters are being measured and recorded at Toowoomba, Queensland.

III. DYNAMICAL CLIMATOLOGY

Our climate is the result of complicated interactions between many different physical processes in the atmosphere and between the atmosphere and the oceans. It is not yet known to what extent it may eventually be possible to forecast climate, but there can be no doubt that any significant capability would be of immense benefit for human welfare and the economy.

The dynamical climatology research programme is concerned with studying the physical basis of climate with main emphasis on seasonal and year to year time scales. The basic goal is to investigate the possibility of developing a capability to predict significant climate changes and anomalies. Progress is most likely to be achieved by a combination of empirical data studies which can yield information on the underlying mechanisms and theoretical/numerical studies which develop knowledge of these mechanisms and ultimately assemble them in numerical models to represent the climate.

It is likely that in the future considerable progress will be made with "statistical dynamical" climate models. In these, the various key processes are incorporated in parameterized form rather than explicitly as in the detailed numerical models developed primarily for short-term forecasting at the ANMRC (Australian Numerical Meteorology Research Centre). Some of these processes, including transfers from sea or land surfaces to the atmosphere, and aspects of solar and terrestrial radiation, have already been adequately formulated as a result of earlier work in this Division and overseas. But currently, in addition to the cloud-radiation relationship mentioned in Section II, one of the greatest needs is for improved parameterization of large scale atmospheric and oceanic transports. Consequently, a significant part of the research programme will be concerned with developing the insights necessary to meet this need.

Data Studies

Patterns of rainfall and temperature

Pattern analysis, similar to that applied earlier to Australian annual rainfall data, is being carried out for temperature data. Preliminary results suggest that the dominant pattern in year to year variations of mean daily maximum temperature over eastern Australia is related to variations in the 'Southern Oscillation' — as was the case with rainfall. Work continues on a more detailed analysis of seasonal effects in rainfall and temperature patterns.

In another application of this type of analysis, it has been shown that meso-scale rainfall variations in the state of Washington, USA, which had been attributed to local pollution effects, were in fact due to natural variations in the larger-scale atmospheric circulation in conjunction with local orography. This emphasizes that caution is necessary in the interpretation of supposedly urban effects on rainfall.

Floods and droughts

Some major occurrences of heavy rains and of droughts in Australia are being studied from the regional and hemispheric synoptic data. The objective is to gain evidence as to the underlying dynamical mechanisms, with a view to theoretical formulation and recognition of factors associated with the onset of these extreme events.

Rainfall in the Darwin region

An investigation is being made to identify factors associated with anomalies of summer rainfall in the Darwin region.

A principal association appears to be with mean temperature through the depth of the troposphere from Alice Springs to Hobart, in the sense that higher rainfalls go with higher temperatures. There is also evidence that meridional circulation in low latitudes plays a part, as it is found that more rain accompanies stronger wind components from the north at a height of 1½ km and from the south at 12 km. Further investigations are being made in an attempt to explain these relationships.

Sea-surface temperature relationships

Some preliminary analyses have been made of sea surface temperature data for the Tasman Sea and, together with sea level data, for the eastern tropical Pacific Ocean. There is evidence of variations with time scales of several years which, in the case of the eastern Pacific data, appear to be related to the Southern Oscillation. Further work, particularly to investigate possible relationships with Australian rainfall, is proceeding.

Mechanisms and Parameterization

Baroclinic instability theory

Theoretical approaches to the parameterization of large-scale horizontal transports recognise that a dominant part in the transport mechanism is played by wave systems of baroclinic type (i.e. which inherently depend on horizontal temperature gradients throughout the troposphere). The development of these systems is investigated in baroclinic instability theory.

The baroclinic instability problem has been studied for various spherical models in which the atmosphere is approximated by two fluid layers having different temperature and velocity distributions with latitude. For a number of different initial flows involving purely zonal motions, the breakdown into wave-eddies has been examined and their consequent heat and momentum fluxes obtained. Some results from this work are also mentioned under Section V.

There has been a view that the barotropic instability of Rossby waves (not associated with horizontal temperature gradients) may be the major mechanism responsible for the growth of errors leading to loss of predictability in numerical weather prediction models. However, from a theoretical study of both barotropic and baroclinic instabaility for initial flows involving planetary waves in the two-layer spherical models, it has been found that the baroclinic type of instability is by far the more important mechanism.

An examination of the stability of zonal flow in multi-layer spherical models has been commenced, with the aim of determining the effect of incorporating a more realistic vertical structure into the models. Preliminary results are encouraging and show that the inclusion of greater detail in these models reproduces more closely the events occurring in the real atmosphere.

Horizontal eddy transport: diagnostic data studies

Evaluations of the local horizontal eddy heat flux and mean temperature gradient using upper air data from Australian stations reveal for both down-gradient and across-gradient exchange coefficients a distinct 3-tier structure between the surface and 30 km. The angle between the flux vector and the temperature gradient exhibits a fairly steady and systematic change throughout the height and amplitude range sampled. The observed vertical dependence throughout the troposphere and lower stratosphere (except for a departure in the lowest layers which can be accounted for by surface frictional influences) must be related to the vertical structure of the transient waves in the atmosphere which accomplish the local eddy flux.

Further work is planned to ascertain whether a similar relationship occurs in other parts of the globe and whether numerical general circulation models satisfactorily simulate the observed behaviour which is likely to be closely related to the longitudinal variation of climate. As a first step, the geographical distribution of local eddy fluxes of heat and momentum over the southern hemisphere south of about 20°S, as obtained in the ANMRC hemispheric general circulation model, is being calculated and compared with that derived from EOLE balloon trajectories.

Sea-air transfer in anticyclonic regions

An earlier bulk formulation of sea-air fluxes of heat and water vapour has now been extended to take account of free convection which becomes dominant in light wind conditions. It will allow these fluxes to be adequately represented in the typical slack wind situation over the central areas of anticyclones.

A test application of the new relationship has been made by the Bureau of Meteorology in an analysis of lake evaporation data.

For two reservoirs where light to moderate winds prevailed, it was found that, while the conventional bulk formula (without diabatic correction) underestimated the total evaporation by 15 and 30 per cent, the new technique gave in both cases the total evaporation within 4 per cent of a value independently determined (by the heat budget method).

Global Climate

Climate modelling

In climate models over the whole range of complexity, from simple empirical through statistical dynamical to general circulation types, non-linear parameterizations, in particular that for surface albedo with partial ice cover (as exists at present), can lead to solutions representing multiple climate states. Further, in numerical solution of the models, the inevitable truncation errors can produce a variety of spurious climate states.

To examine critically the validity of the climates produced in earlier numerical studies of semi-empirical models, an analytical study was made of the behaviour of time-dependent models of the Budyko type. Various non-linear parameterizations of albedo were employed, and it was found that some of the solutions reported in numerical studies were spurious, and were produced as a result of either truncation errors or the use of somewhat unrealistic albedo parameterizations. The investigation revealed both stable and unstable climate solutions, some of which had not been found in the numerical studies.

Possible effects of global warming

Recent studies around the world suggest that the observed increase in atmospheric carbon dioxide, possibly due to the burning of fossil fuels, may lead to a global warming of the atmosphere by some 1.5 to 3°C in the next 50 to 75 years. This warming would occur preferentially at high latitudes, leading to smaller equator to pole temperature gradients and possibly to a poleward shift of the climate patterns. The implications of such a climate change for Australian rainfall are being explored using the previously established patterns of rainfall distribution in relation to the latitude of the high pressure belt and to the Southern Oscillation. It is possible that the change in rainfall distribution would have significant impact for water supplies and drainage systems.

More generally, such a global climate change would lead to conditions somewhat similar to the medieval warm period when the Vikings settled Greenland and the Polynesians settled New Zealand, or to the earlier 'Climatic Optimum' some 6,000 years ago. It is hoped therefore to relate present knowledge of the patterns of Australian rainfall variations to the growing body of tree-ring and other proxy climate data concerning these earlier warm periods.

Solar cycles and weather/climate

An extensive review of the recent literature on this subject, with emphasis on alleged 11- and 22-yr. cycles, has been made. This has revealed a great deal of poorly-based material in the literature, and it provides little support for any statistically significant connection between solar cycles and the weather, at least of a magnitude having practical importance.

IV ATMOSPHERIC CHEMISTRY

The atmospheric chemistry programme deals with the composition and chemistry of the atmosphere on global, regional and local scales, with particular reference to climate change and atmospheric pollution. Airborne material whether gaseous or particulate, plays an important role in regulating climate; for example CO_2 through its ability to absorb longwave radiation may have a warming influence, whereas particulates, by cutting off incoming shortwave radiation, may have the reverse effect. Many of the substances which control climate occur naturally in the air, but continuing industrialization increases the concentration of those already present and, as well, inserts foreign material. Both features have implications for climate, for the environment (for example, in terms of modifying stratospheric ozone), and for health (as in the case of nitrogen oxides and their contribution to a smog situation).

The aims of the research programme are four-fold:

(1) to establish the background levels of those atmospheric constituents which are important in the context of climate, to locate the sources and sinks of these materials and to develop an understanding of their distribution and movement. (Measurements made at Cape Grim, north west Tasmania — the proposed site for a permanent Australian Baseline Air Pollution Station — are an essential element of this programme and absorb a considerable fraction of the available effort);

(2) to determine the extent to which man's activities are contributing to the overall amount of these substances in the atmosphere;

(3) to relate the knowledge derived from (1) and (2) to possible changes in global climate, to atmospheric pollution and to likely modifications of our environment, especially those which are adverse;

(4) the utilization of these components of the atmosphere as tracers to provide information on the dynamics of troposphere and stratosphere.

Careful monitoring and interpretation of the data are the essence of these investigations.

Carbon Dioxide Background Levels

The need to establish 'background' levels of components of the atmosphere has already been stressed. The extensive, continuing air sampling network (see Figure 1) has now produced five years of high quality data. In many cases the sampling is achieved automatically using equipment built to our own design and which can be operated on aircraft specifically modified for the

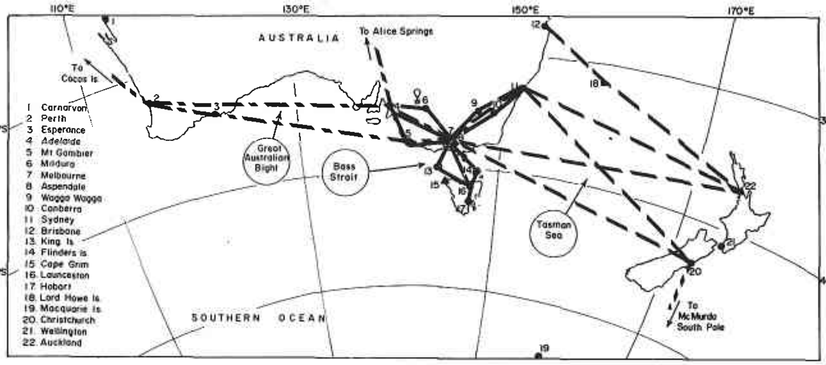

Fig. 1. Air Sampling Network
The dashed and solid lines represent different types of aircraft flying at varying altitudes. There is balloon sampling at Mildura (6) and surface sampling at Aspendale (8) and Cape Grim (15).

purpose. Time and pressure switches which can be adjusted according to the circumstances determine precisely at what stage in the aircraft's flight the sample is obtained. Analysis is carried out subsequently on the ground at Aspendale using an infrared carbon dioxide analyser. During the course of this programme it has become evident that CO_2 is well mixed throughout the atmosphere and the sampling frequency has been adjusted as necessary. The success of this sampling programme owes much to the excellent support received from the air transport group (Department of Transport), Qantas and TAA.

Recently these measurements have been augmented by others from Cape Grim in north west Tasmania — the proposed site for the Australian Baseline Air Pollution Station. (See cover picture, and, for greater detail, elsewhere in this section).

Interpretation of the first five years of data is currently underway: tentative indications are that the concentration of atmospheric CO_2 is increasing on average at about 0.8 ppmv. yr^{-1} (i.e. ¼% yr^{-1}). At first sight these results are in sharp contrast to the known quantities of CO_2 being added to the atmosphere through the burning of fossil fuels, at a rate equivalent to 2.35 ppmv. yr^{-1}. The measured increase is believed to be a result of the anthropogenic input and the natural exchanges with the oceans and biosphere. An interesting feature is the year-to-year variation in the rate of accumulation of carbon dioxide in the atmosphere (see Table 1). It is possible that this is due to variations in the exchange of carbon dioxide between the atmosphere and the equatorial Pacific Ocean, the latter acting as a source or sink depending, amongst other things, on the air/sea surface temperature differential.

Carbon Isotope Studies

The stable carbon isotope ratio, C^{13}/C^{12}, is different in each of the major carbon reservoirs. Thus simultaneous measurements of atmospheric variations in both concentration and isotope ratio can be used to determine the magnitude of exchange as well as the reservoir with which exchange has taken place. Investigations have commenced into the space and time variations of this ratio in the southern hemisphere atmosphere.

In an attempt to describe past variations in the atmospheric C^{13}/C^{12} ratio and the manner in which these have been influenced by industrialization, the carbon in the growth rings of trees has been extracted and analysed. Results obtained using trees from Tasmania show that during this century C^{13}/C^{12} decreased up until about 1940; since then there has been a continual increase. If the ratio in tree rings represents that in the free atmosphere, this implies that the atmospheric CO_2 concentration has been influenced by inter-reservoir exchanges in addition to the simple dilution due to CO_2 release from fossil fuel combustion.

A significant correlation between the secular variation in tree ring isotope ratio and regional temperature provides a method for describing paleotemperatures in Tasmania where 2000 year old trees are available for analysis. The reason for this correlation is not understood and is relevant to the interpretation of the isotope ratio record.

The initiation of this work was made possible through the collaboration of the Antarctic Division of the Department of Science who made a mass spectrometer available to us. In order to expedite these analyses the Division has recently acquired its own instrument.

Ice cores and ancient atmosphere

Some progress has been made in the development of techniques for the extraction of gases trapped in Antarctic ice. No results are available at this stage.

Improvements in instrumentation and measurement

Work has commenced on the development of an infrared CO_2 analyser which differs from conventional non-dispersive infrared (NDIR) instruments in that it depends on solid state rather than microphonic detection. The advantage of the new instrument will be its insensitivity to vibration and it will be used extensively on aircraft.

When CO_2 concentrations are measured using NDIR analysis, it is necessary to dry the air to avoid interference from water vapour. The drying procedure modifies the density of CO_2 in the sample: a simple relationship has been deduced to convert measured CO_2 density to ambient density. More importantly, an analysis of the simultaneous eddy-diffusion of heat, water vapour and CO_2 has shown that when measurements are made of concentration gradients or the covariance of CO_2 concentration and velocity, the CO_2 density must be expressed relative to dry air at a fixed temperature to obtained correct CO_2 flux determinations. These findings have relevance to the measurement of atmospheric fluxes of all trace gases and are especially significant in the use of eddy-covariance techniques.

Ozone

In the stratosphere

The existence of ozone in the earth's atmosphere and the vital part it plays in filtering out harmful short wave radiation have been known for many years. Only recently however has it been realized that man's activities, which often result in the injection into the atmosphere of large quantities of gases and particulates, could lead to a significant reduction in ozone. At Aspendale the concentration of atmospheric ozone has been measured and its distribution in time and space investigated for over 20 years. Originally used as an indiciator of stratospheric winds it is now studied in its own right. The possible threat of damage to the ozone layer through destructive interaction with the by-products of industry make it essential to maintain a continuous check on ozone levels.

The monitoring network currently comprises stations at Cairns, Brisbane, Aspendale, Hobart, Perth and Macquarie Island. An additional Dobson Spectrophotometer has been obtained from the Weapons Research Establishment Salisbury; following completion of repairs and calibration this instrument will be installed at Alice Springs. A new observing station there will fill the network gap in Central Australia and make the coverage reasonably adequate for this part of the world. Routine fortnightly ascents using Mast-Brewer sondes have also continued at the Division's field site near Aspendale.

The long term trend in ozone is being continually monitored. The decrease in ozone observed at Aspendale between 1956 and 1974 is consistent with stratospheric cooling and a weakening of the meridional component of stratospheric winds — both over the same period. Whilst there are a large number of factors which influence ozone amount, overwhelming evidence indicates that the decrease of ozone at Aspendale is largely due to changes in circulation rather than chemistry. Since 1974 there has been a slight increase in ozone over Aspendale.

More detailed analysis of the effect of haze scattering shows that the observed O_3 trend can be partly explained in terms of secular aerosol scattering not appropriately taken into account in the past. The problem is being investigated and the results so far suggest that about 50% of the apparent change in the trend of ozone concentration can be attributed to scattering effects.

An analysis of results of the first eight years of the Aspendale ozone sounding programme has shown that the variations of ozone concentration are principally on synoptic and subsynoptic time scales — except near the primary ozone maximum around the 40 mb level, where seasonal variations are dominant. Throughout most of the atmosphere's depth, year to year variations account for less than 10 per cent of the total variance. The long-term trend component does not exceed 4 per cent at any level, underlining the need for adequate statistical sampling if long-term trends are to be detected with any confidence.

During the total solar eclipse in October 1976, a Dobson Spectrophotometer was used to make some ozone measurements at Aspendale. As might be expected there was an *apparent* increase in ozone during the eclipse i.e. a decrease in ultra-violet radiation recorded at the ground.

At the surface

Surface ozone is monitored continuously at Macquarie Island and at the Cape Grim baseline station, Tasmania. These stations have relatively clean air so that measurements can be regarded as background levels: and the data obtained are being interpreted in terms of the natural ozone cycle. Additional information from the studies concerns the destruction rate of ozone on various natural surfaces, e.g. soil, vegetation and water.

Regular monitoring of ozone in the surface air at Aspendale was terminated at the end of 1975 after 10 years of measurement. Results are being analysed in the context of urban pollution processes.

Oxides of Nitrogen

The oxides of nitrogen are a relatively new area of study for us. They have been introduced because of the key role they play in reactions that produce photochemical smog in the lower troposphere and control ozone in the stratosphere. The particular compounds are nitric oxide (NO) and nitrogen dioxide (NO_2), collectively referred to as NO_x and nitrous oxide (N_2O).

Tropospheric NO_x results mainly from bacterial reduction of nitrogenous compounds in the soil; the remaining NO_x being attributed to anthropogenic sources, primarily high-temperature combustion processes (in automobiles, power plants, etc.).

Photochemical smog normally occurs in urban areas as a result of man-made NO_x which can increase the concentration of the gas by a factor of 100 or more over the natural background level. Smog episodes occur under light wind conditions and in the presence of strong solar radiation.

NO_x

It is most important to be able to distinguish between natural and anthropogenic sources of these oxides and to detect any local and/or global trends. To achieve this goal a chemiluminescent detector specific for nitric oxide/nitrogen dioxide has been designed and built in the Division. It is several times more sensitive than the best commercial instruments and for the first time allows reliable measurements of nitrogen oxides to be made in the background air. Following automation of the sampling unit, the instrument will be installed at Cape Grim and will provide a continuous measurement of nitrogen oxides in clean surface air. The instrument has also been used to study the uptake and exhalation of nitrogen oxides at the earth's surface. Initial results indicate that substantial losses of NO occur from soil surfaces. The influence of soil and atmospheric conditions on this process is being investigated.

Measurements of total atmospheric NO_2, using a modified Dobson Spectrophotometer as described in our last Biennial Report, have been extended to Perth. Two years of data of NO_2 at Aspendale and Brisbane have shown seasonal variations which closely parallel those for total ozone. The Varian diffraction grating spectrophotometer has also been modified to measure atmospheric NO_2 and is currently under test.

The formation and destruction of stratospheric ozone has been the subject of intense worldwide investigation in recent years. It is known that nitrogen oxides provide the main chemical control of this ozone. NO_x has a lifetime of only several days in the troposphere and it is therefore unlikely that significant amounts can be transported to the stratosphere. It is generally accepted that stratospheric NO_x results from the oxidation of nitrous oxide present in the region.

N_2O

This gas is produced naturally by microbiological activity at the earth's surface in a process called 'denitrification'. It has no proven tropospheric sink and it is eventually transported to the stratosphere. It has been postulated recently that the increasing production of artificial nitrate fertilizers will increase denitrification and cause a significant decrease in stratospheric ozone by the end of the century. A similar effect could result from the direct injection of NO_x into the stratosphere by supersonic aircraft.

Nitrous oxide is measured daily at Aspendale and information on spatial variation gained by analysing samples obtained in the CO_2 programme. Nitrous oxide appears to be well-mixed in the troposphere and lower atmosphere. Ten months of measurement at Aspendale reveal no significant trend in concentration although short-term fluctuations are present. The role of the oceans in the N_2O budget is to be investigated.

Planned

A programme designed to make in situ measurements of stratospheric nitric oxide is expected to commence towards the end of 1977. The venture, which is in co-operation with the Dept. of Chemistry, York University, Canada, involves a balloon-borne chemiluminescent detector built by the Canadian group and used successfully in the Northern Hemisphere. A successful outcome to this work will make it possible to conduct a valid comparison between the nitric oxide content of the two hemispheres and allow theoretical predictions to be tested. Early detection of changes in the concentration of the gas in the atmosphere, whether due to natural or anthropogenic causes, depends solely on maintaining an adequate and regular stratospheric monitoring programme.

Halocarbons

Halocarbons are of interest particularly because of the hypothesis that, should they find their way into the stratosphere, the chlorine produced by their breakdown will react destructively with ozone. These substances are largely man-made (e.g. CCl_3F is believed to be entirely so) and, particularly in the northern hemisphere, they serve as excellent trace materials in studies of urban air and interhemispheric exchange. This work is relatively new and its commencement two years ago was made possible through the co-operation of Dr. Lovelock (U.K.) and the loan of an electron-capture gas chromatograph. We have subsequently acquired our own instrument and the programme has grown considerably.

Measurements of atmospheric halocarbons have been made for about one year at the Australian Baseline Air Pollution Station (Cape Grim) and on air samples collected during the Division's aircraft air sampling programme. The first 12 months of data from Cape Grim show an average tropospheric concentration of CCl_3F (Freon-11), CCl_4 (carbon tetrachloride) and CH_3CCl_3 methyl chloroform) of 120, 159 and 40-60 pptv (parts per 10^{12} by volume) respectively at the end of 1976. (See Figure 2). Based on 12 months of Cape Grim data and 18 months of aircraft data, atmospheric CCl_3F concentrations appear to be increasing at about 18% yr^{-1}. A small but consistent difference between in situ and grab sample measurements has yet to be explained.

A comparison of recent CCl_3F data with other published values, and the rate of accumulation of the gas in the southern hemisphere implies a large scale interhemispheric eddy diffusion coefficient of 0.5×10^{10} cm^2s^{-1}.

A study of the concentration of CCl_3F in urban Melbourne under nocturnal inversion conditions has indicated the usefulness of the gas as a tracer of urban air. The work has also provided emission data which are consistent with an emission inventory based on manufacturer's useage rates.

Standardization of measurements has been achieved by an ongoing programme of interlaboratory calibrations with Washington State University, National Bureau of Standards and National Aeronautic and Space Administration.

A theoretical study has been made of carbon tetrachloride in the global atmosphere. Man made emissions to the atmosphere from industrial sources have been evalued for the period 1914 to 1973. The mechanisms of loss of carbon tetrachloride from the atmosphere by gas phase reaction, ultraviolet photodecomposition, and dissolution and breakdown in the oceans were evaluated. A simple model using the emissions and loss mechanisms predicted global average concentrations similar to those observed. It was concluded that carbon tetrachloride in the global atmosphere is probably man made, not naturally occurring as have been suggested previously.

TABLE 1

Annual mean carbon dioxide concentration in the mid-troposphere over south eastern Australia and Bass Strait. Concentrations corrected for carrier gas errors and expressed according to the WMO 1974 CO_2 Calibration Scale.

Date	No. of Samples	Mean CO_2 Concentration (ppmv)	Increase (ppmv yr^{-1})
Mar. 1972 — Feb. 1973	204	327.22	
			1.23
Jan. 1973 — Dec. 1973	231	328.45	
			0.43
Jan. 1974 — Dec. 1974	236	328.88	
			1.10
Jan. 1975 — Dec. 1975	225	329.98	
			0.29
Jan. 1976 — Dec. 1976	264	330.27	

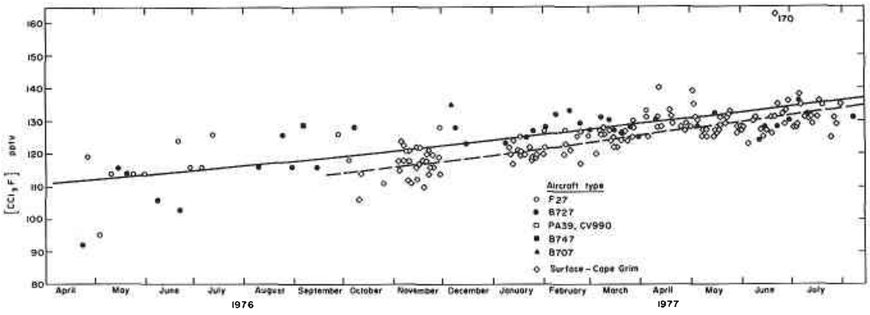

Fig. 2.
Atmospheric CCl_3F (freon-11) concentrations (parts per trillion (10^{12}) by volume) measured over Australia by aircraft (————) and at the surface at Cape Grim (— — — — —).

Radioactivity, Particulates and Heavy Metals

The Division's concern with atmospheric radioactivity centred largely on Be_7, a naturally occurring radionuclide primarily produced in the polar stratospheres and which can be used as a tracer to investigate tropospheric and stratospheric circulation. Suitable fission products, resulting from the nuclear weapons testing programme in the south Pacific area, have also been used as tracers.

Radioactivity data obtained between 1971 and 1977 from our surface air sampling network ranging from 9°S to 43°S suggests that an injection of air enriched with Be_7 occurred at about 20°S in the spring with a secondary injection at high latitudes in summer.

A measure of the total particulates in near surface air is useful as an indicator of atmospheric pollution and as a low level tracer of surface motions. Such particulate concentrations have been measured for some 6 years at five sites extending along the east Australian coast and for 5 years at one location in Papua New Guinea. Seasonal means vary between 20 and 70 ug m^{-3} for mainland Australia, with lower values for Tasmania and Papua New Guinea. No long term trends in particulate concentrations are apparent at the southern locations but downward trends are observed at two northern sites.

Concentrations of some heavy metals (Pb, Cd, Ni, Zn, Cu, Fe, Cr, Mn) in particulates collected at the Hobart sampling site have been measured using flame atomic absorption spectroscopy. Although total particulate concentrations are low in Hobart, the concentrations of some heavy metals in the particles are similar to those found in north American urban sites.

For various reasons these three research projects will be terminated when processing of existing data is completed.

Stratospheric Water Vapour

Monitoring of stratospheric water vapour over Australia has continued using balloon-borne infrared radiometers, roughly five or six times a year. The measurements indicate an increase in mixing ratio from 1973 to late 1975 followed by a decrease up to early 1977. The mean ratio between 15 and 21 km is approximately 2.7 ppmm.

The Australian Baseline Air Pollution Station

The Division continues its role as advisor to the Commonwealth Department of Science in the establishment of guidelines and instrumental techniques for the operation of an Australian baseline atmospheric monitoring station. A very considerable effort has been put into the design, construction and installation of equipment and the analysis and interpretation of the resulting observations. A temporary station has now been established at Cape Grim, N.W. Tasmania. The following atmospheric components are monitored regularly: carbon dioxide, ozone, freon 11, freon 12, N_2O, CCl_4, direct solar radiation, diffuse solar radiation, ultraviolet solar radiation, erythemal ultraviolet radiation. In addition aitken particle concentrations, large particle concentrations, particle size distribution are measured by the Division of Cloud Physics. These measurements are supported by the common surface meteorological observations.

V. GEOPHYSICAL FLUID DYNAMICS

The geophysical fluid dynamics programme aims to advance the understanding of the dynamical processes in the atmosphere and in the oceans in so far as they affect the atmosphere. The basic philosophy followed since the inception of these studies at Aspendale is to use simple models of a particular phenomenon in isolation, combining wherever possible a quantitative theoretical approach with experimental observation. In this way an understanding of the complex motion of the real atmosphere is built up step by step.

Topics have been chosen in response to or in anticipation of needs or likely developments of local or national importance. We have sought to tackle subjects in which physical and conceptual understanding rather than mathematical labour is wanting and which are within the limitations of the available technical resources. Nevertheless useful progress has been made on selected topics within a wide range, from fine scale diffusion to global waves and currents, and including some physical oceanography. In addition to studying the phenomena basic to motion in a rotating and stratified medium, simulations of more direct application such as dispersion of chimney plume effluents are also being undertaken. Developments in our laboratory include a lengthening of the stratified towing tank to 30 feet and the construction of precision salinity sounding equipment.

The Stable Medium: Internal Waves

Air flow over mountains

It was previously reported that careful laboratory experiments have revealed deficiencies in existing theoretical models describing the flow of a stably stratified airstream over mountains.

As a result of these observations a new "quasi-linear" theoretical model has been developed, which is applicable when the stratification is weak or the mountain height is small but finite. This model provides a description and explanation of the upstream motions observed in the experiments, and indicates the limitations of the classical linearized leewave theory. The latter, though useful because of its simplicity, has been shown to be ill-posed in a mathematical sense. Further experiments have been undertaken to test the new model quantitatively; some measure of agreement has been found, although the comparison is as yet inconclusive. Some non-linear effects of a hydraulic character have also been observed, and described by a multi-level hydrostatic model.

Amplification of finite wave packets

Laboratory experiments have demonstrated that non homogeneous, fine internal waves, even in discrete 'packets', can be strengthened parametrically by a large-scale wave field.

Theoretical calculations quantitatively confirm observations that such packets spread as beams and evolve rapidly toward quadratic 'triad' resonance with the large wave. This adds weight to predictions that the process is important in the deep oceans.

Energy partition in internal wavebreaking

A start has been made on an experiment to define a law governing the partition of energy between viscous dissipation and potential energy gain in a saturated internal wave field. The intention is to provide a 'closure' to the energy cascade and also to quantify the diffusivity of such fields as they occur in the free atmosphere and the ocean.

The quasi-biennial oscillation

A dominant feature observed right around the equatorial stratosphere is the periodic reversal of the zonal wind above 20 km. This phenomenon earns its title from its period, which varies between two and three years. One theoretical explanation is that the oscillation occurs because of the upward transfer of momentum by global-scale equatorial waves. Selective absorption of this momentum gives the overlying zonal flow the appearance of a gradually descending transverse wave. Existing theory has been modified to remove certain fundamental inconsistencies and to improve its generalized application. The major features of the oscillation have been successfully reproduced in simple applications of the revised theory, and laboratory simulations in an annular tank are now underway.

An observational study has been made of stratospheric zonal winds at a series of Australian upper air stations ranging from Lae (7°S) to Casey (66°S). This has shown that a coherent oscillation extends well beyond the tropics; it is evident at all stations, though strongest near the equator and weakest at about 35°S. A systematic variation in the vertical phase propagation of the oscillation is also evident. Strong downward phase propagation occurs in low latitudes, decreasing steadily to zero at about 40°S, with weak but significant *upward* phase propagation in higher latitudes.

Inertia — Gravity waves in the atmosphere

Data from serial soundings at Laverton (20 km SW of Melbourne) are being analysed to see if inertia-gravity waves can be detected. Preliminary examination indicates a weak downward phase propagation of near-inertial period consistent with the presence of such waves.

Convection Studies

Convective penetration

The previously reported laboratory experiments simulating the convective penetration of an atmospheric temperature inversion by ground heating have been postponed awaiting the use of better controls for the even distribution of injected salt water used to represent ground heating. Further analysis of earlier results has found that the downward buoyancy flux through the convective interface is about 0.2 times that occurring at the 'ground' surface, in rough agreement with other workers, but now seeming to depend on overlying stability.

Penetration of inversions by plumes

When a buoyant plume from a fixed local source such as a chimney, encounters an overlying inversion, the proportion of the plume passing through the inversion, and the proportion trapped beneath and within the inversion depend upon, among other things, its buoyancy relative to the strength of the inversion. The fraction which fails to penetrate clearly infuences the degree of subsequent fumigation at ground level. Laboratory experiments simulating such a situation, using a towed source are now in progress with the object of deriving useful laws for the vertical deposition profile.

Rotation and Global Dynamics

Baroclinic instability on a sphere

The instability of a large scale zonal flow over a sphere has been studied in a very general context, using a two-layer model. The results of several previous investigators have been extended and shown to be mutually consistent. Some general properties of the north-south fluxes of heat and momentum have been deduced from the results.

Heat and momentum transfer by baroclinic waves

A reliable parameterization of heat and momentum transfer by mid-latitude eddies is a major requirement of climate models. A basic theoretical study of such transfers has confirmed and to an extent generalized, some of the results of numerical studies of baroclinic waves. In particular it clarifies the role of momentum transport in maintaining the jet stream (whose structure in turn influences the momentum fluxes). In addition some general results concerning the vertical structure of heat transfer have been obtained which suggest an explanation for the observed local maximum in eddy heat flux in the region of the mid latitude tropopause. Other aspects of this work are outlined in Section III.

Rotational turbulence studies

The previous report described an experiment simulating the kinematic effects of fine scale convective mixing on a homogeneous uniformly rotating fluid. Intense vortices implying an efficient diffusion of angular momentum, were observed. An enlarged and improved version of the apparatus has been built with the facility to introduce buoyancy and variable rotation (beta) effects. This has been used mainly to study in greater detail the structure of vortices with the aim of isolating the dynamical cause of the phenomenon. To this end an experiment currently in progress incorporates an inner freely rotating drum coaxial with the closed cylindrical experimental chamber. When the whole system is rotated, the introduction of mixing causes a relative anticyclonic rotation of the drum. This effect is consistent with a vorticity expulsion mechanism accompanying localized weakening of angular momentum gradients. Using the apparatus an *ad hoc* simulation of intense localized elevated convection in a rotating storm was undertaken. This revealed the formation of vertical anticyclone/cyclone eddy pairs at the periphery of the mixed region. In evolution the cyclones intensified and the anticyclones weakened, lending weight to the possibility that angular momentum diffusion may have a part to play in tornado genesis. One dynamical explanation for the phenomena observed in these studies is the nonlinear interaction of inertial modes. Some numerical calculations have shown that with axisymmetric modes core vorticity could indeed be strengthened significantly.

Beta plane studies

In collaboration with J. Whitehead and A. Colin de Verdiere at Woods Hole Oceanographic Institution a number of polar beta plane experiments were done using a weak, zonally periodic peripheral forcing in a rotating cylinder. Mean zonal currents could be generated by the poleward radiation of Rossby wave momentum, in conformity with the Taylor vorticity diffusion hypothesis. By superimposing a mean zonal current, critical layer absorption of these waves was induced and measured, representing the first quantifiable laboratory realization of this geophysically important process.

Physical Oceanography

Surface mixed layer

In addition to the oceanographic relevance of several of the topics mentioned above, work has commenced upon numerical models aimed at describing the surface mixed layer of the ocean through which the influence of the ocean upon the atmosphere is transmitted. The initial study is of a zonally uniform equatorial region as a model of the central Pacific Ocean.

Internal tides

Following the theoretical work on internal tides described previously, work in this area has concentrated on testing the theoretical models with observations obtained off the coast of north-west Africa by a joint British-German expedition. This is one of the world's most important upwelling and fishing areas, and the general flow pattern is quite complex and variable. The results to date indicate that the internal tidal models are valid in the broad sense. However, the situation is more complex than originally anticipated, with observations indicating the possible pressure of bottom-trapped edge waves generated by topographic variations along the continental slope. Results from this study will be useful in understanding similar situations in the Australian region, particularly the north-west shelf where tidal motions are very large.

The 'Southerly Buster'

The Southerly Buster is a sudden and dramatic cool change which is frequently observed on the NSW south coast and is associated with the passage of a front across south-east Australia. A simple mechanistic model for this phenomenon, consistent with its observed properties has been developed and embodies two main concepts. Firstly, "geostrophic adjustment" calculations show that a moving front encountering a mountain range such as the Australian Divide will speed up on the southern side (and slow down on the northern side), forming a coastal jet. Secondly, if ambient conditions are favourable, the front of this jet will develop a gravity current structure, producing the familiar "roll" cloud and abrupt change in wind and temperature.

VI. REGIONAL METEOROLOGY

This aspect of the Division's work deals with the micro- and meso-scale properties of the near surface air. Well above the ground the movement of air masses is governed by relatively large 'synoptic' scale patterns but nearer the earth's surface, events are profoundly influenced by regional factors such as water-land contrasts and topography. In attempting to elucidate the physical processes occurring at these low levels and on these scales we undertake investigations which are amenable to both theoretical and experimental treatment and which will provide solutions to practical problems. A good example of this approach is our present work in the Latrobe Valley.

The Valley is potentially an area of considerable industrial development, particularly of power generation, coal hydrogenation and perhaps, in the future, gas manufacture. An important issue at this stage is the likely impact of industrialisation on the local environment. Although intrinsically well suited as a field laboratory the observations provided by the national weather observing network in the region are not dense enough to reveal the detailed structure. We have therefore engaged in a collaborative venture with the SEC of Victoria, and have just completed two years of daily observations of winds and stability. These observations are the basis of studies to:

1. assess the effect of existing and new works,
2. establish a network of monitoring stations,
3. facilitate design and planning of new works, and
4. validate numerical models that will be required in the future for environment management.

In conjunction with this study a 'light switched' time-lapse cine camera has been employed to obtain an 18 months record of fog occurrence and smog movement.

Atmospheric diffusion studies

Present techniques for estimating the diffusion and transport of contaminants in the atmospheric boundary layer are based upon measurements made on sites chosen for their uniformity. These techniques are virtually untested in regions of topographically influenced flow. In an attempt to rectify this deficiency field trials are being conducted in which sulphur hexafluoride, detectable in minute amounts (10^{-12} v/v) ,is being released from selected sites and sampled downward using automatic sequential samplers. Proof trials have so far shown the method to be capable of giving empirical estimates of atmospheric diffusion coefficients, and work is continuing to measure these coefficients under various representative conditions.

Slope winds and katabatic flows

At night, air cooled on the slopes of valleys drains downwards in a thin layer. This 'katabatic' drainage flow represents the major dispersing process under calm atmospheric conditions. An observational study, supported by theoretical evaluation, is being made to obtain a profile of this flow on a selected slope to clarify the initiation, maintenance, duration and dispersion processes, and to provide means of parameterizing them for numerical models integrating 'slope' and 'valley' effects.

Results obtained so far show that in addition to clear skies, the background wind field is critical to the initiation and maintenance of a definable katabatic flow. It appears that the driving force for the flow, generated by radiational cooling of the surface layers at night, is balanced not by surface drag but by interaction with the ambient wind field. The katabatic flow mixes with the ambient air, grows in thickness and is slowed by this entrainment. The direction and strength of the ambient wind plays a major role in directing and balancing the katabatic flow.

This study has called for a means of sounding vertically the profile of temperature, humidity and wind direction and speed up to a height of 1 km. A new facility has been developed at the Division for the purpose. To a tethered balloon which can be raised and lowered by winch is attached a small instrument package which makes the required measurements and telemeters the results to the ground.

Surface boundary layer studies

Work has centred mainly upon improving equipment for the I.T.C.E. (referred to in greater detail under Section VI) and analysis of data from that experiment. Development has included a modified version of the precision profile equipment used on the Daly Waters expedition described in the Division's 1973/75 report. This provides continuous digital records of accurate wet and dry bulb temperature ($\pm$.002°C) at five heights between one and sixteen metres.

A cable-suspended drag plate lysimeter of improved design was built and installed at Deniliquin as part of the I.T.C.E. Analysis of data from this experiment is now complete, and attention has turned to pilot measurements of flux of heat and momentum on valley slopes, to complement the slope wind study mentioned above. Construction of a new portable profiling boom is nearing completion. This will enable measurements to be made at selected (logarithmically separated) height intervals up to 20 metres above the surface, all operations, including attention to the instruments, being carried out at ground level.

VII. AIR-SURFACE INTERACTION

A primary objective of the Division since its inception has been to improve understanding of the mechanisms involved in exchanges of heat, water vapour and momentum between the atmosphere and the underlying surface (land and sea), to understand how the processes are influenced by the nature of the surface and atmospheric stability, and to determine their relationship with the larger-scale aspects of atmospheric flow.

Much of the work in these areas over the last 2 years has been concerned with analysis and interpretation of the KOORIN (Daly Waters, 1974), AMTEX (East China Sea 1974 and 1975), and ITCE (Conargo, 1976) experiments, referred to below.

Some of the work concerned with air-sea interaction and described in earlier reports has continued. Other aspects, particularly those involving the development of a free-floating instrumented buoy have been curtailed and some staff diverted to higher priority areas.

Surface Aerodynamic Roughness

A consideration of drag coefficient over land shows large variations between continents, with drag arising from flow over mountains contributing some 20 per cent of the overall drag of the land surfaces of the globe.

The geographical distribution of aerodynamic roughness length on a grid-scale of (2.5° x 2.5°) has been determined for the Australian continent, based on maps of vegetation and other surface types. Mean monthly surface stress throughout the year has then been determined from geostrophic winds inferred from grid point values of average surface pressure.

A comprehensive review of observations of wind stress and wind profiles over the ocean, reported in the literature over the past 10 years, suggests that the surface (neutral) drag coefficient increases as the square root of wind speed, at least up to 20-25 m s^{-1}. Beyond this and up to the limit of 50 m s^{-1} for which information is available, hurricane data imply a continuing increase. The observations additionally indicate a value of the von Karman constant of 0.41 ± 0.025.

These studies provide detailed information permitting surface roughness to be incorporated into large scale numerical models of the atmosphere.

Aspects of vertical turbulent transfer above tall vegetation have been studied using data from the KOORIN experiment. These suggest, for daytime conditions, that considerable modification of the 'smooth' surface flux-gradient relation (see earlier Annual Reports) occurs in an air layer (above the surface) of depth 3-5 times the height of the main surface roughness elements. Within this 'transition' layer, eddy diffusivities are considerably greater than those predicted from the Prandtl-von Karman mixing length theory (for 'smooth' surface relations).

In determining the profile scaling lengths z_O and z_T (for momentum and heat respectively) the heterogeneous nature of the surface made it necessary to use airborne and ground-based radiometers to measure surface temperature. The ratio $z_O/z_T \triangleq 10$ was consistent with values found for homogeneous natural vegetated surfaces in an earlier study. This has important implications in the determination of surface temperature by extrapolation of the temperature profile measured well away from the surface. The difference in surface temperature between levels z_O and z_T may be several degrees C in typical daytime conditions — a significant fraction of the air-surface temperature difference controlling the vertical heat transfer.

Further analysis is aimed at identifying the factors determining the depth of the transition layer, and the way in which the modified flux-profile relations depend upon the nature of the surface.

The Air Mass Transformation Experiment (AMTEX) 1974 and 1975

The data obtained from the AMTEX experiment have been used to investigate the performance of sensors used to measure turbulent fluxes, and relate optimum values of the turbulent fluxes, through transfer equations, to local and large-scale wind and temperature parameters characterising surface and boundary flow over the ocean.

Sets of data from several sensor arrays separated by distances ranging from 1 m to 60 km have been compared. At the smallest separation, comparison between two CSIRO arrays and an Okayama University array has allowed a more precise determination of sensor response corrections to the eddy covariances. In addition, suitable corrections for sensor tilt and mean air flow distortion have been determined, using algebraic and electronic methods. At the greatest separation, combination of the fluxes allowed approximation of the grid-scale, i.e. large-scale, surface fluxes. These fluxes were then utilised in the surface and boundary layer transfer relations, both approaches giving comparable results in terms of predicted flux but requiring modification of heat transfer coefficients commonly found in the literature. For the surface layer, differences between the heat and water vapour coefficients suggest different physical mechanisms for vertical transfer from the air-sea interface.

Work is in progress refining the boundary layer heat transfer coefficient using data from the AMTEX and WANGARA (Hay 1967) expeditions (see earlier Annual Reports). In addition the boundary layer wind structure is being investigated in terms of momentum flux parameterization. Effects of baroclinity and trajectory curvature are included, in terms of the variation of the geostrophic (or gradient) wind with height and the relation to observed winds throughout the mixed layer.

Future studies will involve boundary layer structure over ocean (AMTEX) and land (KOORIN) and its dependence upon surfaces fluxes.

The International Turbulence Comparison Experiment (ITCE) 1976

During October 1976 the Division hosted ITCE 1976 which was conducted at Conargo, near Deniliquin, N.S.W.

Scientists from USSR, USA, Canada, Japan and France co-operated with officers of this Division in conducting the experiment. The object was to assemble a large data base of turbulence records to permit a detailed investigation of the performance of sensors designed to measure horizontal and vertical wind speed, temperature and humidity. In all, 52 half hour runs were recorded and these are currently being analysed.

In addition, this Division provided a detailed micrometeorological record of eddy fluxes of sensible heat, latent heat and momentum; wind, temperature and humidity profiles up to a height of sixteen metres; lysimeter evaporation, net radiation, ground heat flux and wind direction. It is intended ultimately to achieve a definite statement on various flux-profile relationships.

Considerable collaborative assistance was provided by colleagues in the Division of Environmental Mechanics in the verification of humidity profiles and in the determination of shear stress using two drag plates.

Sea-air transfer in light winds

A bulk formulation of sea-air fluxes of heat and water vapour has been developed to take account of free convection which becomes dominant in light wind conditions. This has particular relevance in the development of climate models for representing sea-air transfer in anticyclonic regions, and is mentioned under this topic in section III.

Evaporation

For many years the Division has conducted research into the evaluation of evaporation from land and water surfaces and has collaborated with the Australian Water Resources Council and other bodies in the practical implementaion of suitable methods.

However two types of surface have always presented difficulties: terrain covered with tall vegetation such as forests, and water storages covered with evaporation-reducing films such as cetyl alcohol. Recently a new method, believed to be suitable for these cases, has been developed, and preliminary tests using data from earlier expeditions to Lake Eucumbene, Kerang and Hay suggest that the method should be successful in practical application.

Measuring water vapour in the stratosphere — preparing an infra-red radiometer.

VIII PERSONNEL: AWARDS, APPOINTMENTS, RETIREMENTS AND AFFILIATIONS

Awards

In 1976, Dr. C. H. B. Priestley, Chairman of the Environmental Physics Research Laboratories, was awarded the Order of Australia for distinguished service in the field of science. He was also awarded the Carl-Gustav Rossby Research Medal (the highest honour bestowed by the American Meteorological Society) for his work on atmospheric dynamics.

Dr. G. W. Paltridge received the 1975 David Syme award for original research. He was also awarded a D.Sc. from the University of Queensland.

Dr. R. Bell received a Ph.D. from Monash University.

New Appointments

In May 1975, Mr. I. Bird from the Antarctic Division of the Department of Science joined the Division. His principal role is to co-ordinate the activities of the mechanical and electronics laboratories.

Dr. R. A. Plumb joined the Division from the British Meteorological Office in February 1976. He is involved in theoretical work on atmosphere dynamics.

In April 1976, Dr. C. R. Roy who for two years had been a guest scientist at the Juelich Atomic Research Establishment (West Germany) was appointed to the Division to work on air chemistry.

Later in the same year Dr. R. O. R. Y. Thompson from the University of Bergen, Norway took up an appointment to work on theoretical and data analysis studies of the atmosphere and oceans.

Retirements

In January 1977, Dr. C. H. B. Priestley, formerly first Chief of this Division relinquished the position of Chairman, Environmental Physics Research Laboratories.

Since the last Biennial Report, two founder members of the Division have retired: Dr. F. A. Berson whose field was synoptic meteorology, and Mr. R. J. Taylor whose interest was atmospheric turbulence.

Affiliations

Dr. G. B. Tucker:— Vice-Chairman of the Joint Organizing Committee for GARP; Chairman of the AAS (Australian Academy of Science) National Committee for GARP; Chairman of the National

Drifting Buoy Programme Committee; Associate Editor 'The Mathematical Scientist'; member of the Pacific Science Committee, the Australian Institute for Defence Science, the International Commission on Dynamic Meteorology and the ANMRC Policy Advisory Committee.

Dr. A. J. Dyer:— member of the Executive Committee, International Association for Meteorology and Atmospheric Physics; IAMAP Commission on Atmospheric Chemistry and Global Pollution; International Council of Scientific Unions, Committee on Space Research (COSPAR), Working Group 6; AMTEX Steering Committee; AAS National Committee on Problems of the Environment (SCOPE); AAS National Committee for Geodesy and Geophysics — Chairman, Sub-Committee on Meteorology and Atmospheric Physics; Department of Science Baseline Atmospheric Pollution Working Group; Editorial Panel 'Boundary Layer Meteorology'.

Dr. R. N. Kulkarni:—member of the International Ozone Commission of the IAMAP; Chairman, IAMAP Working Group on Atmospheric Ozone.

Dr. G. W. Paltridge:— member of the International Radiation Commission of I.A.M.A.P.: ad hoc Working Group for JOC of GARP — Extended Cloudiness and Radiation; International Commission on Atmospheric Electricity, Working Group No. 3; invited expert to the JOC (GARP) Board for Climate Studies.

Dr. G. I. Pearman:—member of the WMO Working Group on Air Pollution Measurement.

Mr. I. C. McIlroy:— member of the International Commission on Irrigation and Drainage, Working Group on Evapotranspiration.

Dr. A. D. McEwan:— member of the AAS National Committee on Icebergs.

Mr. I. Bird:— member of the AAS National Committee for Antarctic Research, Sub-committee on Meteorology.

Mr. E. K. Webb:— continues as a member of the Reference Panel for Research Project: Field Study of Evaporation of the Australian Water Resources Council.

Dr. K. T. Spillane:— adviser to the Victorian State Ministry of Conservation, Westernport Bay Environmental Study Group.

Dr. A. B. Pittock:— Technical Secretary to AAS Committee on Climatic Change.

Mr. W. Shepherd:— member of the Victorian Ministry of Conservation Desk Study of Gippsland Lakes Catchment Area Environmental Study.

IX. OVERSEAS VISITS AND OTHER ACTIVITIES

Overseas Visits

During the period, Dr. G. B. Tucker undertook the following overseas visits:

In September/October 1975 he attended a meeting of the Joint Organizing Committee (JOC) of the Global Atmospheric Research Programme (GARP) in Tokyo, visiting en route the Royal Observatory, Hong Kong.

In March 1976 he undertook a five-day visit to New Zealand to discuss collaborative research projects with the Director, New Zealand Meteorological Service, and to familiarise himself with relevant research in New Zealand universities.

En route to a GARP meeting in Nairobi in mid 1976, he visited the British Meteorological Office, the National Institute of Oceanography, and Reading University for discussions with the Chairman, WMO Working Group on Tropical Research.

He visited Moscow in September 1976 to attend a meeting of JOC Officers calling on the way at Geneva for discussions with the Secretary of the Joint Planning Staff of JOC and the GARP Activities Office (WMO).

In January 1977 he attended a meeting of the JOC Board of GARP in Geneva. Later, in April, 1977, he spent two weeks in Stockholm to attend the XIII Session of the JOC Board of GARP and an FGGE (First GARP Global Experiment) Research Co-ordination Conference.

Dr. A. J. Dyer was overseas between August and October, 1975, principally to attend a series of conferences, namely the XVI General Assembly of the International Union for Geodesy and Geophysics at Grenoble, France; a WMO/IAMAP Symposium at the University of East Anglia, U.K., and an Organizing Committee for AMTEX in Tokyo. The opportunity was taken to spend two weeks at the Institute of Atmospheric Physics in Moscow and to make a series of shorter visits to research establishments in Europe and the USA involved in atmospheric chemistry and numerical modelling of the atmosphere.

Dr. C. M. R. Platt is currently spending a year in America as a Visiting Research Fellow at the Co-operative Institute for Research in Environmental Sciences, run jointly by the University of Colorado and the National Oceanic and Atmospheric Administration (NOAA) at Boulder, Colorado. His work is concerned principally with the interaction of clouds and radiation. Whilst there he is visiting and giving seminars at CSU (Fort Collins), NCAR, and the University of Colorado. In June 1977 he attended and presented several papers to the 8th International Lidar Conference at Philadelphia.

Between February and September 1975 Dr. A. D. McEwan was the guest of the Woods Hole Oceanographic Institution, Woods Hole, Massachussetts as Rossby Fellow. While there he spoke at M.I.T. and Harvard in Boston, at Johns Hopkins University in Baltimore, Dalhousie University, Halifax, Nova Scotia, N.C.A.R. in Boulder and Colorado State University, Fort Collins, Colorado. He also participated in the 9th Hurricane Conference in Miami and the XVI General Assembly of the IUGG in Grenoble, France, and visited several centres in the U.K.

As a result of receiving a Nuffield Foundation Travelling Scholarship, Mr. I. E. Galbally is spending a year in the Division of Environmental and Medical Sciences, AERE, Harwell, England. During this period, he will be studying the uptake of sulphur dioxide over forests and fields using the eddy correlation technique.

In 1976, Dr. G. W. Paltridge spent six months at the GARP Activities Office at WMO Geneva taking part in the organization of the GARP Climate Programme. He has since attended a number of GARP climate related meetings, an Ocean Modelling conference in Helsinki, a Cloud Radiation Workshop in Boulder, and a meeting of the JOC Climate Board in Stockholm.

Mr. E. K. Webb visited the Atmospheric Physics Group at Imperial College London for three months in 1975 with brief visits to other centres in England and the USA to gain information on current research in large-scale dynamics related to climate modelling.

In March 1976, at the invitation of the National Bureau of Standards (NBS) and the National Aeronautics & Space Administration (NASA) Dr. G. I. Pearman attended a conference at Boulder on Atmospheric Sampling and Analysis for the Determination of Atmospheric Concentrations of $CFCl_3$, CF_2Cl_2 and N_2O. Later in the same month, as a member of the Australian National Committee for SCOPE (Special Committee on Problems of the Environment) he attended a SCOPE Workshop on Biogeochemical Cycling of Carbon at Ratzeburg, Germany. Invited by the Energy Research and Development Administration (ERDA), Dr. Pearman attended in March 1977 a Workshop on the Environmental Effect of Carbon Dioxide from Fossil Fuels Combustion at Miami, Florida.

In August 1976, Dr. P. J. Fraser attended, and presented a paper to the International Conference on Stable Isotopes at the Institute for Nuclear Science, DSIR, Wellington, New Zealand.

Mr. W. Shepherd, in October 1975 spent a month in the Republic of Korea as WMO Consultant in agricultural meteorology. The purpose of his visit was to assist in the establishment of the UN-funded Meteorological Research and Training Institute, Seoul.

Various members of the Division have also presented papers and taken part in a variety of symposia, workshops, conferences etc. organized at a national level.

From Overseas

The Division was fortunate to have a nine-month visit from Dr. W. L. Smith, Chief of the Radiation Branch of the National Environmental Satellite Service of NOAA. Dr. Smith injected a number of new initiatives into the lidar programme: in particular, he was instrumental in the preliminary development of a satellite-borne lidar project involving both this Division and the United States — a new technique which holds out strong hope for satellite monitoring of surface pressure.

From the Meteorological Office, Bangkok, Mr. Somwang Martchaipoon obtained training at the Division in atmospheric ozone measurement and interpretation. His visit was sponsored by the Colombo Plan.

Other Activities

Mr. I. E. Galbally has given a course of lectures on the composition and chemistry of the atmosphere to honours students at the University of Melbourne.

Standards

The Division continues its work as an accredited laboratory of the National Association of Testing Authorities (NATA) in the fields of low speed anemometry, and solar and thermal radiation. This Association exists to maintain various standards and for this purpose makes use of selected laboratories, both government and industrial. The total number of instruments received for calibration fluctuates from year to year, but typically is several hundred.

Water quality

A regular weekly check of water quality in terms of organic pollution has been made on sea water samples obtained from three local sites around Port Phillip Bay. Using the u.v. radiation absorption technique developed in the Division and described in the last Biennial Report, the results indicate a weak seasonal variation in the amount of pollution, a maximum occurring in Spring. However, confirmation is needed and the work continues. Attempts to pin-point the chemical nature of pollution have not yet succeeded although it is known that hydrocarbons generally have absorption bands in the wavelengths used.

X. PUBLICATIONS

ANATI, DAVID, A., GAD ASSAF, and RORY O.R.Y. THOMPSON (1977)

Laboratory models of sea straits. *J. Fluid Mech.,* **81,** pp. 341-351.

BAINES, P. G. (1976)

The stability of planetary waves on a sphere. *J. Fluid Meoh.,* **73,** part 2, pp. 193-213.

BAINES, P. G. (1977)

Comments on "On the asymmetry of the land-breeze sea-breeze circulation" by R. A. Pearson, *Quart. J. Roy. Met. Soc.,* **103,** No. 436, p. 375.

BAINES, P. G. and A. J. TROUP (1977)

'The Southerly Buster — A coastally trapped gravity current?' Two day Workshop on Fronts, Royal Meteorological Society, Australian Branch. Conf. Handbook, pp. 11.7-11.9.

BARTON, I. J. and D. F. ROBERTSON (1975)

Measurements of erythemally effective uv radiation and total ozone content. *Nature,* Letter, **258,** No. 5530, pp. 68-69.

BENNETT, MARTIN, A., ROMEO CHARLES and PAUL J. FRASER (1977)

Oxidative addition of monosilanes to planar iridium (I) complexes and carbonylation of the resulting adducts. *Aust. J. Chem.* **30,** pp. 1201-1211.

BENNETT, MARTIN, A., ROMEO CHARLES and PAUL J. FRASER (1977)

Reactions of mono- and di-substituted acetylenes with planar iridium (I) complexes and carbonylation of the resulting adducts. *Aust. J. Chem.,* **30,** pp. 1213-1219.

BERSON, F. A. and G. BAIRD (1975)

A numerical model of cumulo nimbus convection generating a protected core. *Quart. J. Roy. Met. Soc.* **101,** No. 430, pp. 911-928.

BIRD, I. G. (1976)

Thermal Ice Drilling. In: 'Ice-Core Drilling.' J. F. Splettstoesser, Ed. Univ. of Nebraska Press, USA., pp. 1-18.

BIRD, I. G. and P. H. SULZBERGER (1976)

Australian unmanned geophysical observatories in Antarctica. Proc. of IAGA meeting on Unmanned Observatories in Antarctica. T. Nagata, Ed. Nat. Inst. of Polar Res. Japan, Aug. 1976, pp. 52-75.

COLLINS, B. G. (1975)

Aspendale — Regional radiation centre for the south-west Pacific. *Aust. Met. Mag.,* **23,** No. 3, pp. 47-60.

DYER, A. J. (1975)

Measurement of turbulent fluxes by Fluxatron and Nifti techniques. *Atmos. Tech.* No. 7, pp. 25-29.

FRANCEY, R. J. (1975)

A cassette integrating data-logger. CSIRO Div. of Atmos. Phys. Tech. Paper No. 27.

FRANCEY, R. J., D. J. PACK and G. F. RUTTER (1976)

Computer interface for cassette integrating data-logger. CSIRO Div. of Atmos. Phy. Tech. Paper No. 28.

FRASER, P. J. B. and G. I. PEARMAN (1976)

Sampling methods in atmospheric halocarbon analysis. *Clean Air,* **10,** p. 33.

FRASER, P. J. B., FRANCEY, R. J. and G. I. PEARMAN (1976)
Stable carbon isotopes in tree rings as climatic indicators. Proc. Int. Conf. on Stable Isotopes, Lower Hutt, Wellington, New Zealand.

FRASER, P. J. B. and G. I. PEARMAN (1977)
Atmospheric CCl_3F, CCl_4 and CH_3CCl_3 concentrations over south east Australia during November 1976. NASA Tech. Memo. TMX-73630, pp. 145-154.

FREDERIKSEN, J. S. (1976)
Non-linear albedo-temperature coupling in climate models. *J. Atmos. Sci.* **33,** No. 12, 2267-2272.

GALBALLY, I. E. (1976)
Man-made CCl_4 in the atmosphere. *Science,* **193,** pp. 573-576.

GALBALLY. I. E. (1977)
Measurement of nitrogen oxides in the background atmosphere. Air Pollution Measurement Techniques. Special Environmental Report No. 10, WMO No. 460.

GARRATT, J. R. and R. J. FRANCEY (1975)
Turbulence flux measurements by CSIRO during AMTEX 1975. Fourth AMTEX Study Conference, Scientific Report, No. 8, Tokyo, pp. 94-96.

GARRATT, J. R. (1977)
Aerodynamic roughness and mean monthly surface stress over Australia. CSIRO Div. of Atmos. Phys. Tech. Paper No. 29.

GOODMAN, H. S., NOLLER, B. N., PEARMAN, G. I. and H. BLOOM (1976)
The heavy metal composition of atmospheric particulates in Hobart, Tasmania. *Clean Air,* **10**, pp. 38-41.

HICKS, B. B. and H. S. GOODMAN (1977)
Seasonal and latitudinal variations of atmospheric radioactivity along Australia's east coast (150° E. Longitude). *Tellus,* **29,** pp. 182-188.

HYSON, P., GARRATT, J. R. and R. J. FRANCEY (1977)
Algebraic and electronics corrections of measured uw covariance in the lower atmosphere. *J. Appl. Meteorol.,* **16,** No. 1, pp. 43-47.

IMBERGER, JORG., RORY THOMPSON and CHRIS FANDRY (1977)
Selective withdrawal from a finite rectangular tank. *J. Fluid Mech.* **78,** part 3, pp. 489-512.

KULKARNI, R. N. (1975)
Measurements of NO_2 using the Dobson Spectrophotometer. *J. Atmos. Sci.* **32,** No. 8, pp. 1641-1643.

KULKARNI, R. N. (1975)
Ultraviolet absorption method applied to organic matter in sea water. *Water, Air, and Soil Pollution,* **5**, pp. 231-237.

KULKARNI, R. N. (1976)
Nitrogen dioxide and ozone measurements over Australia. *Quart. J. Roy. Met. Soc.,* **102,** No. 432, pp. 461-464.

KULKARNI, R. N. (1976)
Ozone trend and the stratospheric circulation over Australia. *Quart. J. Roy. Met. Soc.,* **102,** No. 433, pp. 697-704.

KULKARNI, R. N. (1976)
Determination of total ozone in the atmosphere — an invited report to the Radiation Commission of the IAMAP for "Inversion Methods in Atmospheric Radiation Research".

MANINS, P. C. (1975)
Compression of an elastoporous medium. *Int. J. Non-Linear Mech.*, **13,** pp. 75-93.

MANINS, P. C. (1976)
Intrusion into a stratified fluid. *J. Fluid Mech.*, **74,** part 3, pp. 547-560.

MANINS, P. C. (1976)
Mixed region collapse in a stratified fluid. *J. Fluid Mech.*, **77,** part 1, pp. 177-183.

MANINS, P. C. (1977)
Fumigation and a laboratory experiment. *Weather*, **32,** No. 6, pp. 221-228.

McEWAN, A. D. (1976)
Angular momentum diffusion and the initiation of cyclones. *Nature*, **260,** No. 5547, pp. 126-128.

McEWAN, A. D. and G. W. PALTRIDGE (1976)
Radiatively driven thermal convection bounded by an inversion — a laboratory simulation of stratus clouds. *J. Geoph. Res.*, **81,** No. 6, pp. 1095-1102.

McILROY, I. C. (1975)
A sensitive low-cost weighing system. "Recent advances in measurement technology" IICA National Symposium, Inst. of Instrum. and Control — Australia, July, 1975.

PALTRIDGE, G. W. (1975)
Global dynamics and climate — a system of minimum entropy exchange. *Quart. J. Roy. Met. Soc.*, **101,** No. 429, pp. 475-484.

PALTRIDGE, G. W., DILLEY, A. C., SHEPHERD, W. and D. J. CONNOR (1975)
The Rutherglen experiment on Sherpa Wheat: Environmental and Biological Data II. CSIRO Div. of Atmos. Phys. Tech. Paper No. 26.

PALTRIDGE, G. W. (1976)
A context of climate research within GARP — Report of 1st Meeting of JOC Board for Climate Studies, GARP publication.

PALTRIDGE, G. W. and C. M. R. PLATT (1976)
Radiative processes in meteorology and climatology. Vol. 5 of 'Developments in Atmospheric Science', Elsevier Scientific Publ. Co. Amsterdam, Oxford and New York. 318 pp.

PALTRIDGE, G. W. and D. PROCTOR (1976)
Monthly mean solar radiation statistics for Australia. *Solar Energy*, 18, pp. 235-243.

PEARMAN, G. I. (1976)
Global atmospheric pollution and climate: An overview with reference to the role of baseline monitoring. ANZAAS Congress, Hobart.

PEARMAN, G. I. (1977)
The carbon dioxide — climate problem: recent developments. *Clean Air*, **11,** No. 2, pp. 21-26.

PEARMAN, G. I. (1977)
Further studies of the comparability of baseline atmospheric carbon dioxide measurements. *Tellus*, 29, pp. 171-181.

PEARMAN, G. I., R. J. FRANCEY and P. J. B. FRASER (1976)
Climatic implications of stable carbon isotopes in tree rings. *Nature*, 260, No. 5554, pp. 771-772.

PEARMAN, G. I. (1977)
Measurement of atmospheric composition at the Australian Baseline Atmospheric Monitoring Station. Analytical Techniques in the Determination of Air Pollutants. Proc. Clean Air Society Symposium, Melbourne University, pp. 16-22.

PEARMAN, G. I. and D. J. BEARDSMORE (1977)
Atmospheric carbon dioxide concentrations over south east Australia during November 1976. In: 'Interhemispheric survey of minor upper atmospheric constituents during October-November 1976.' NASA Tech. Memo TMX-73630, pp. 158-166.

PITTOCK, A. B. (1975)
Climatic change and the patterns of variation in Australian rainfall. *Search,* **6,** No. 11-12, pp. 498-504.

PITTOCK, A. B. (1977)
On the causes of local climatic anomalies, with special reference to precipitation in Washington State. *J, Appl. Meteorol.,* **16,** No. 3, pp. 223-230.

PLATT, C. M. R. (1976)
Infrared absorption and liquid water content in stratocumulus clouds. *Quart. J. Roy. Met. Soc.,* **102,** No. 433, pp. 553-562.

PLATT, C. M. R. (1976)
A solar aureole radiometer for atmospheric aerosol studies. *J. Appl. Meteorol.,* **15,** No. 12, pp. 1323-1326.

PLATT, C. M. R. (1977)
Lidar observation of a mixed-phase altostratus cloud. *J. Appl. Meteorol.,* **16,** No. 4, pp. 339-345.

PRIESTLEY, C. H. B. and A. B. PITTOCK (1977)
Inhomogeneity of satellite-derived climatological data. *Bull. Am. Met. Soc.* **58,** No. 3, p. 258.

SAWFORD, B. L. (1976)
Meteorological aspects of pollution dispersal in the atmosphere. Environmental Engineering Conf. 1976. Inst. of Engineers, Australia, National Conference Publication No. 76/7.

SHEPHERD, W. (1975)
Inclusion of plant moisture status in combination-method estimates of pasture evaporation. *J. Hydrology,* **26,** No. 3/4, pp. 199-207.

SHEPHERD, W. (1976)
Indices of plant moisture status: some comparisons within and between species. *J. Appl. Ecol.* **13,** pp. 205-209.

SPILLANE, K. T. and P. E. DEXTER (1976)
Design waves and wind in the Australian Tropics. *Aust. Met. Mag.* **24,** No. 2, pp. 37-58.

THOMPSON, RORY O. R. Y. (1976)
Climatological numerical models of the surface mixed layer of the ocean. *J. Phys. Oceanog.,* **6,** No. 4, pp. 496-503.

THOMPSON, RORY (1977)
Reply to Comments on "Climatological numerical models of the surface mixed layer of the ocean". *J. Phys. Oceanog.,* **7,** No. 3, pp. 470-471.

THOMPSON, R.O.R.Y. (1977)
Observations of Rossby waves near site D. *Prog. Oceanog.,* **77,** pp. 1-28. Pergamon Press G.B.

TUCKER, G. B. (1976)
Research and services: differing attitudes in the science of meteorology. *Weather,* **31,** pp. 104-113.

TUCKER, G. B. (1977)

An observed relation between the macroscale local eddy flux of heat and the mean horizontal temperature gradient. *Quart. J. Roy. Met. Soc.,* **103,** No. 435, pp. 157-168.

TUCKER, G. B. (1977)

Towards the study of global atmospheric pollution. *Search,* **8,** No. 5, pp. 147-151.

WEBB, E. K. (1975)

Evaporation from catchments. In: 'Prediction in Catchment Hydrology' (ed. T. G. Chapman and F. X. Dunin), (Aust. Acad. Sci., Canberra), pp. 203-236.

WEBB, E. K. (1977)

Convection mechanisms of atmospheric heat transfer from surface to global scales. Proc. Second Australasian Conf. on Heat and Mass Transfer, Feb. 1977 (University of Sydney), pp. 523-539.

WEBB, E. K. and G. I. PEARMAN (1977)

Correction of CO_2 transfer measurements for the effect of water vapour transfer. Proc. Second Australasian Conf. on Heat and Mass Transfer, Feb. 1977 (University of Sydney), pp. 469-476.

XI. STAFF

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