

**CSIRO**  
**Division of Atmospheric Physics**  
**Research Report 1977-1980**

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**Division of Atmospheric Physics**

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COVER PICTURE

Australia as seen from the Japanese Geostationary Satellite  
on February 20, 1979.

## I. INTRODUCTION

The atmosphere and oceans are much too large to enable cause-and-effect relations to be studied experimentally on the scale of weather and climate. Consequently, in addition to observing natural events and relating them to the processes at work, repeatable experiments need to be performed via proxies. Two substitutes used are physical-mathematical models, often using sophisticated computer techniques because of the complexity of the systems and governing equations, and experiments with fluids in the laboratory, studying phenomena which theory indicates may be scaled up to represent what occurs in the atmosphere and oceans. Both these techniques are vital to the armoury of the Division and have afforded significant insights on nature in the full scale.

Laboratory modelling of rotating and stratified fluids receives special mention. The experiments, involving water tanks, probe the basis of various phenomena in the oceans and atmosphere. They have stimulated research into direct practical problems associated with the weather and also into essential dynamical aspects of other major projects of the Division — climatology and the study of atmospheric constituents.

On the international scene, the outstanding event has been the highly successful 12-months implementation phase (December 1978 — November 1979) of the First GARP Global Experiment (FGGE), also known as the Global Weather Experiment. Divisional scientists made major contributions to the extensive planning and preliminary sub-programmes associated with the FGGE. The reward will be a unique global data set of the behaviour and structure of the atmosphere and the ocean surface. Subsequent research should lead to further understanding of both weather and climate in the southern hemisphere and particularly the Australian region. Of the many observing systems developed for the FGGE, the southern hemisphere drifting ocean buoys and polar-orbiting and geostationary satellites have great potential for future use in the study of atmospheric physics. For this reason the Division plans to give high priority to direct-access satellite imagery and remote sounding for studies of weather and climate. This will be in accord with a burgeoning cold front research programme and the growing importance of studies of climate and climate change.

The cold front research programme which involves collaboration particularly with the CSIRO Division of Cloud Physics and the Bureau of Meteorology is a natural development for the Division's work on the boundary layer and meso-scale processes.

Research on longer atmospheric time scales involves theoretical and numerical studies of the physical basis of climate. This includes dynamical processes, thermodynamical concepts, the morphology of Australian and southern hemisphere climate, and the important cloud/radiation interaction. Atmospheric constituents which exercise a vital influence on the climate system are studied in an associated programme. In this latter area, one of the sub-programmes exciting much attention concerns the carbon cycle in the atmosphere and the role of CO<sub>2</sub> in the climatic balance.

## II. GEOPHYSICAL FLUID DYNAMICS

The geophysical fluid dynamics programme is concerned with the basic dynamical processes that determine the motions of the atmosphere and the oceans. Despite the obvious differences in density, compressibility and other properties, these motions are governed by the same physical laws, and there are many similarities in the basic processes and phenomena concerned. The underlying purpose is to provide the elements needed for the mathematical analysis of weather on local, regional and global scales, and the approach is to synthesize these processes in a manageable model by a combination of analytical, numerical and laboratory simulation techniques.

The programme is largely composed of discrete studies. Falling under four general headings, representative examples of recently completed and continuing work are given below.

### **The Stable Medium**

Both the atmosphere and the ocean are for the most part stably stratified; that is, their temperature distribution is such that if displaced, the medium will tend to return to its original level. The motion is consequently wavelike in character, and the vertical exchange of matter and momentum is dependent heavily on the properties of these waves.

### **Airflow Over Mountains.**

In the atmosphere the most important generator of waves is ground topography. An extensive programme of laboratory experiments simulating a uniform flow over idealized two dimensional obstacles has been undertaken to test theoretical descriptions of the resulting motion. The results cover a comprehensive range of defining parameters, and in particular explore the occurrence of 'upstream influence', where the effect of the obstacle is transmitted upwind in the form of a wave. Linearized perturbation theory has been shown to fairly describe the properties of the waves behind the mountain providing it is small in height. New theoretical work has established that the upstream influence depends on non-linear effects and on the presence of a limiting vertical feature such as a temperature inversion resulting in waves being trapped beneath it.

In collaboration with the New Zealand Meteorological Service, data from their weather observing network have been examined for evidence of upstream influence. These data were found to be somewhat less than optimum, and a special observing programme is planned.

A laboratory study has also been carried out of stratified flow over mesh barriers placed transversely in the stream. The primary aim was to determine the conditions governing the partition of flow of fluid over and through the barrier. The principal findings were that the character of the flow depends primarily on a Froude number,  $F$ , (based on fluid speed, density stratification and barrier height). If  $F > 0.5$  most of the fluid approaching the barrier flows over it; if  $F < 0.5$  all the fluid below a certain

height (dependent on  $F$  and mesh size) flows horizontally through the gaps, and above this height the fluid flows over the barrier in a nearly two-dimensional fashion.

### **Energy Partition in Internal Wavebreaking.**

A large part of the energy going into internal waves is ultimately lost by breaking or overturning. The resultant mixing weakens the temperature gradient, and in so doing increases the static potential energy of the system. In defining the net effect of internal waves on stratified media it is therefore necessary to determine the fraction of the incoming energy which is transferred in this way to potential energy. To make a direct measurement of this energy partition, a laboratory experiment was performed in which internal waves were continuously forced at breaking level. With allowance made for residual losses, the fraction was found to be about one quarter. In distinction from previous attempts at measurement there appeared to be little dependence on mixing intensity.

### **Convection Studies.**

Convection occurs when air is heated above the temperature of its surroundings, resulting in a 'plume' if the supply of heated air is continuous or in a 'thermal' if it is released as a parcel. Many natural convection phenomena are characterized by plume or thermal behaviour; and because the mechanism by which energy is distributed within the troposphere is important — though little understood — the phenomenon is the subject of several studies. The principal ones are described below.

### **Penetration of Inversions by Plumes.**

If a buoyant plume is discharged beneath an elevated inversion, only part of the emission will penetrate while an (often large) proportion will be trapped below. Laboratory experiments simulating this behaviour have been completed, and a new theoretical model has been devised which agrees well with the results, and which can be applied to real situations. Previous working rules were found to be too conservative in predicting inversion penetration, by a factor up to about three. Further experiments are underway to aid in a critical examination of commonly applied basic plume-rise formulations.

### **Laboratory Simulation of Cumulus Cloud Dynamics.**

Cumulus clouds are characterized by an internal conditional liberation of latent heat which provides their buoyancy. This distinguishes them from simple convection from a localized source. Despite intrinsic dynamical differences, models of cumulus convection have relied on results of convection experiments of the latter type. A new experimental technique correctly simulating the essential features of cumulus convection has now been developed. Water is the working fluid, and the cloud fluid is saturated with helium which comes out of solution in the form of minute bubbles as the environmental pressure falls. Entrainment, detrainment and environmental convergence are successfully represented.

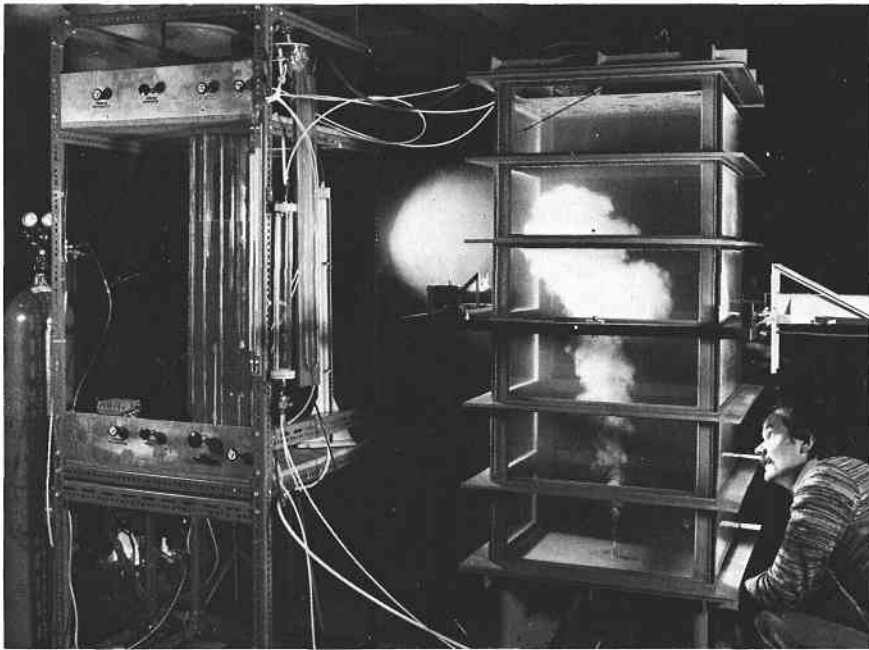


Fig. 1.

A novel approach to the simulation of latent heat release in a developing cumulus cloud. The tank contains water which represents the atmosphere. The 'cloud', consisting of water in which helium has been dissolved under pressure, is forced through a hole in the base of the tank. As it rises, the decreasing hydrostatic pressure allows the helium to come out of solution, creating buoyancy in a manner resembling the release of latent heat accompanying condensation in a cloud.

Detailed experiments so far have concentrated on the behaviour of thermals. These have revealed essential and important differences between 'moist' thermals with height-dependent buoyancy release and 'dry' thermals. Internal buoyancy release evidently suppresses toroidal circulation in the thermal material, thereby preventing homogenization of the thermal and inhibiting entrainment. The thermal therefore enlarges less rapidly, rises faster and penetrates further than a 'dry' thermal. The results are consistent with observed cumulus cloud behaviour and are being analyzed with a view to providing a more accurate representation of the bulk properties of cumulus convection.

### **Rotation and Global Dynamics.**

In two important respects the Earth provides a framework for an abundance of complex phenomena in the moving fluid skin that is the atmosphere. Firstly, this skin closes on itself so the motions transmit their effect around the globe in the manner of horizontally moving waves of a variety of wavelengths and amplitudes. Secondly the framework is rotating, and while the smaller phenomena are not strongly influenced, the rotation becomes a dominating factor for processes of a few hundred kilometres scale, and even on a much smaller scale where locally the rotation is

intense, such as in tropical cyclones or tornado-producing thunderstorms.

Recent research in this area has included the following studies.

#### **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 name 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. A revision of existing theory and a much simplified model of the oscillation was described in the previous biennial report. The theory has now been validated by the results of a laboratory experiment. In this experiment, internal gravity waves were generated at the base of an annular tank of salt-stratified water. The waves generated an oscillatory zonal flow in the tank, whose structure was qualitatively similar to the atmospheric oscillation and quantitatively in good agreement with theoretical prediction. Apart from its direct relevance to the quasi-biennial oscillation the experiment also provided confirmation of certain principles of momentum transfer by waves in a manner which had not previously been practically demonstrated.

As yet, no numerical general circulation model has successfully reproduced the quasi-biennial oscillation. Theory suggests that this failure is due to inadequate resolution and excessive artificial dissipation in such models. A new numerical model designed to provide a realistic simulation of the oscillation is presently under test.

#### **Planetary Wave-Zonal Flow Interaction.**

Planetary waves — large scale wave motion of zonal wave number less than about 5 — are a major feature of the atmospheric circulation. About one-half of the total poleward transfer of heat in the atmosphere is accomplished by these waves. The broad-scale weather pattern in any region is strongly influenced by the structure of the overlying tropospheric planetary wave pattern. In the stratosphere, planetary waves are apparently responsible for 'sudden warmings' of the winter pole, through interaction with the strong westerly jet (the 'polar night jet') which is observed in the mid-latitude winter stratosphere.

Our conceptual understanding of planetary wave behaviour is based on linear theory. Interaction with the mean zonal flow is ignored in such theories. A series of studies have now been carried out to investigate the idea that the feedback processes associated with the interaction between the wave like parts of the motion and the background zonal flow have a profound influence on planetary wave structure. So far the studies have been based on very simple theoretical models but some potentially important phenomena have been highlighted. Numerical models of so called wave-mean flow interaction are being developed with a view to applying these theoretical ideas to more realistic representations of the troposphere and stratosphere.

### **Momentum Transfer by Weak Eddies.**

Much of the inter-latitude exchange of westerly momentum in the atmosphere is known to be due to the action of synoptic scale 'eddies'. Similarly, the eddies in the ocean evidently transfer momentum to enhance currents such as the Gulf Stream. Theoretical predictions indicate that where there exists a gradient in the effect of the earth's rotation (the so-called 'beta' effect) westerly momentum is gained in regions where the eddies are strongest (or are being forced) at the expense of the momentum of surrounding regions.

A laboratory experiment has been conducted to test quantitatively these predictions. An open cylindrical dish of water was spun axially so that the centrifugal deformation of the surface introduced a beta effect. Eddies were forced within a radial region by creating a travelling system of suction and ejection through the porous bottom of the dish. As predicted, a sinuous westerly jet was created over the forcing region. Further, it was demonstrated that, in accordance with predictions, when forcing was provided by deforming the bottom into a travelling system of ridges and troughs the same effect could not be obtained because the drag imposed on the fluid by the deformations counteracts the forcing provided by them, and only weak mean flows can be induced.

### **Rotational Mixing and the Genesis of Tropical Cyclones.**

It has often been convenient in theoretical and numerical models of the atmosphere to assume that eddy motions too small to be explicitly resolved have effects resembling those of molecular diffusion. Laboratory experiments previously reported have demonstrated that this is not the case when rotation becomes even moderately strong, and that one consequence is the concentration of regions of high rotation rather than a diffusion of them.

The results imply a redistribution of angular momentum over scales larger than the eddies themselves. New numerical models have successfully simulated the process for rotational waves forced strongly enough to become centrifugally unstable, and further laboratory experiments have explored the properties of rotating fluids over wider ranges of conditions. Among the phenomena revealed is 'super-rotation', characterized by internal mean rotations greater than those at any boundary.

Experiments specifically related to tropical cyclone genesis have also commenced, and it is found that with confined convection characteristic of tropical disturbance cloud clusters, the mechanics of the high-level cirrus outflow strongly influence the intensification of the infant vortex.

### **Physical Oceanography.**

A modest part of the Division's programme has been devoted to physical oceanography on those topics where the necessary data and expertise have been available and where it is likely that the result will shed light on atmospheric phenomena. Two examples of this work are described below.

### **Transport Through the Tasman Sea.**

Using oceanographic data from the CSIRO Division of Fisheries and Oceanography, an estimate has been made of the transport through two closed box sections of the Tasman Sea, with the particular object of estimating the amount of water carried by the East Australian current. From the results it appears that though 50 to 60 megatons per second was being transported on one occasion, the current was virtually absent on another, pointing to the highly transient character of the current.

### **Dropsonde Development.**

Work is underway on the development of a simple dropsonde device which when released from a vessel, sinks to the bottom and then returns to the surface. If three of these devices are deployed simultaneously a measurement of net volume flux and direction can be determined from their relative positions on resurfacing, providing water depth is not great. The devices are intended for an experiment constituting a first attempt to measure directly the volume flux through Bass Strait.

### III. CLIMATOLOGY AND ATMOSPHERIC RADIATION

Anyone aware of the errors in 24-hour weather forecasts will not be surprised to learn that predicting climate — the "average weather" of the next month, year, or century, and so on — is not yet possible. We assume that it is possible in principle but we are still at the stage of asking 'what principle?' We do not know which scientific avenue will ultimately make an impression on the problem. We do know that it will involve something other than the techniques conventionally used for current short-term forecasting.

Thus the study of climate forecasting presents an immediate difficulty. On the one hand the limitation of resources demands a focus on only a few aspects of the problem. On the other, we still need to probe from many different directions simply to determine the more promising avenues. Our approach is inevitably a compromise. There is a wide spread of activity which might be classed as innovative and there are the 'focussed' projects which, among other things, relate closely to the UN-sponsored GARP Climate Programme — an international research effort presently being developed to address the climate problem.

#### **Innovative Projects.**

Activities in this category include attempts to relate Australian climate to anomalies of sea-surface temperature in the Pacific; searches for common factors in the atmospheric circulation associated with Australian-region 'extreme events' such as major drought and flood; and attempts to simulate present-day global climate using the recently developed techniques and results of irreversible thermodynamics.

One study in this category concerns a basic problem associated with predicting long-term climate change, namely that even if a theory is devised which indicates that the climate will change in such and such a manner, there may be too little data to check the outcome of the theory before the event occurs. An obvious approach is to apply the theory to the 'prediction' of different climates of the past. The difficulty then is that information on past climates is likely to prove too sparse and to consist merely of surface properties such as the extent of ice sheets, large-scale rainfall patterns and possibly, the surface temperature. In particular, details will probably be needed of the atmospheric circulation at the time since this is the basic parameter of a climate regime. One project of this type has involved examination of the climate of the Australian region during the last glacial maximum — the late Quaternary of about 18000 years ago. A description appears later in this section.

#### **Focussed Projects.**

One major project is a theoretical examination of the fundamental physics of turbulent flow patterns in a medium surrounding a rotating sphere. The aim is to explain the character and position of the atmospheric long-waves which exist in both hemispheres and which, to a large extent, control the weather and climate of a particular region. 'Long-wave prediction' is an essential intermediate step in the general process of climate prediction.

On the experimental side, the centrepiece of the work of the radiation group is an investigation of the role of clouds in controlling the radiation energy budget of the earth-atmosphere system (and therefore the climate). This has been a long-standing project of the Division and its importance has been reinforced now that 'cloud radiation feedback' has been identified by the international GARP Climate Programme as one of the basic problems associated with numerical climate prediction. Recently, interest has shifted from lower-level water clouds (about which something at least is now known) to upper-level cirrus clouds. These common ice-particle clouds exert a dominant control on the radiative energy budget of the earth, the study of which is helped considerably by the Division's extensive lidar and infrared radiometric observing system. The remainder of this section describes in more detail the various projects currently under way.

### **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. To what extent it may eventually be possible to forecast climate is not yet known, 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 predicting 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.

One line of research involves "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 exchanges between sea or land surfaces and 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. Currently one of the greatest needs is for improved parameterization of large scale atmospheric and oceanic transports and of interaction between radiation and clouds. Consequently, a significant part of the research programme is concerned with developing the insights necessary to meet this need.

### **Large-Scale Systems: Data and Modelling Studies.**

*Monsoon dynamics and macro-scale climate studies.* Simple coupled ocean-atmosphere models have been used to study the longterm transient features of the Earth climate system. One version includes an interactive ocean, a full hydrologic cycle and the self-determination of

simple cloud distributions. Ultra-long integrations have been undertaken for time periods greater than 20 years. The purpose was to establish ocean-atmosphere relaxation times. The model shows interannual variability in all fields throughout the integration but after an initial perturbation it settles back to cyclic equilibrium in about 4 years. This is heartening as it approximates the scale time estimate of the real mixed layer of the ocean. Such agreement suggests that the model can be used for anomaly studies.

***Numerical simulation of global-scale flow.*** Statistical mechanics has been employed to obtain the time-averaged flow in numerical simulation models describing global-scale atmospheric flow. The manner in which weather forecasts depend on the accuracy of the observations and the number of reporting stations has been investigated and has reinforced the need for a denser station network in the Australian region.

***Hemispheric scale, low-frequency mid-latitude mechanisms.*** Hemispheric data sets (such as the EOLE constant-level balloon data) suggest that, between the strong seasonal and synoptic energy peaks of the southern hemisphere general circulation, there lies considerable variance in intermediate frequency phenomena with time scales of weeks. Diagnostic studies of various data sets show that the transient features exist on the largest spatial scale and appear as physically coherent properties of both the troposphere and stratosphere. New results indicate that these transients, hitherto considered only from their effect on zonal averages, show considerable longitudinal variation. The potential of such properties as an aid to statistical forecasting on a hemispheric scale for several weeks ahead is being considered.

***Floods and Droughts.*** A study of some major occurrences of heavy rainfall and droughts in Australia, based on regional and hemispheric data, is continuing. The object is to find factors associated with the onset of these extreme events, and to gain evidence of the underlying mechanisms with a view to developing theoretical formulation and long-range forecasting techniques.

Attention has been mainly on two particular areal distributions where the rainfall has a relation with larger scale circulations. In the southern Queensland/northern N.S.W. region, the relation is with the Southern Oscillation, while in the Sydney and Adelaide regions there is an inverse rainfall association related to the latitude of the high-pressure belt and the large-scale zonal flow pattern. In both cases, it is found that there is a marked distinction between periods when the relation is strongly evident and periods when it is weak or non-existent. The nature of these differences is being further examined, and it is hoped that the large-scale correlations can be brought into better focus by taking account of other influences.

Particular emphasis is now being directed to features related to the Southern Oscillation. This term refers to changes in the large-scale pressure system over the tropical Pacific region which occur on time scales of up to a few years. They are measured in terms of the mean sea level pressure difference between Darwin and the mid-Pacific. The mechanism

is not understood at present nor are the prospects for predicting its behaviour known as yet. Among a number of variables closely associated with the Southern Oscillation are the east Australian rainfall and, inversely, eastern Pacific sea-surface temperature and equatorial Pacific rainfall.

***Darwin district rainfall.*** A study of associations of the Darwin district monthly rainfall in summer with various meteorological parameters has been continued. For each month, (December, January and February), there is a significant negative association with Darwin pressure over the period studied (1913 to 1978), with the remarkable exception that there is negligible association — in January only — from 1913 or 1946. Examination of the rainfall variations for the northern Cape York peninsula (a monsoon area at about the same latitude), shows that at about the same time here, the reverse happened — in that the association with Darwin pressure changed from strongly negative to zero thereafter. This evident secular change around 1946 has relevance to prediction of rainfall using the Southern Oscillation Index. It appears to be associated with a northward shift in the equatorial trough zone over Australia and with a marked decrease in the persistence of tropical cyclones over the Philippines. The relationships are being studied further using data from both hemispheres.

A description of recent work on the dynamics of monsoons can be found later in this report under the heading 'Tropical Meteorology'.

#### **Mechanisms and Parameterization.**

***Synoptic systems as mechanisms of meridional eddy transport.*** A classification of cloud vortices in the southern hemisphere, observed from satellites, has been used to provide an inventory of the incidence of different stages in the life-cycle of mid-latitude synoptic disturbances as a function of latitude. The role of these different stages in accomplishing meridional eddy fluxes of heat and momentum has been studied. The decaying stages are shown to be vitally important in effecting a strong equatorward flux of momentum. The observed latitude profile of transient eddy flux is thus shown to be strongly influenced by the different stages in the life-cycles of synoptic systems occurring at preferred latitudes. Further implications of these studies bear upon the differences in synoptic behaviour between northern and southern hemispheres.

Case studies of individual synoptic situations and some sequences of development verify the results obtained from the composite study of cloud vortices and eddy flux statistics.

***Stratospheric zonal winds over Australia.*** Upper air statistics at selected Australian stations have been used to further determine details of the structure of the quasi-biennial zonal wind oscillation in the southern hemisphere and, in particular, of the relation between tropical and high latitude features. Phase and amplitude profiles as a function of latitude suggest that a forced oscillation in equatorial regions may be conveyed throughout the tropics by a lateral diffusive process, but for the high latitude phenomenon some other process must be sought.

**Baroclinic development and large-scale transports.** The effects of long quasi-stationary planetary waves on producing preferential regions of development of large-scale depressions in the atmosphere has been studied using numerical methods. It is found that the results of the baroclinic instability theory used, are in a good agreement with the observed regions of most actively developing baroclinic disturbances. Heat and momentum fluxes have also been calculated and their distribution is found to agree with observations.

On the basis of this study a statistical dynamical climate model has been proposed using parameterizations of heat, momentum and other fluxes based on baroclinic instability theory incorporating long planetary waves.

**Cloud-radiation relationships.** A simple radiative model has been developed to explore the dependence of one form of thermodynamical forcing — radiative heating — on cloud and moisture distributions. Critical dependencies are found. The model has been used to study the radiative properties of clouds of various types and heights. The investigation has also been extended by relaxing the constraint of fixed atmospheric state (instead the atmosphere is allowed to adjust convectively) with the object of seeking the temporal variability introduced into a system by cloud. Systems defined by an interactive oceanic lower boundary or land lower boundary are now being considered.

A further study has been completed using the Winter Monsoon Experiment (December, 1978) data set. During the experiment, extensive layers of upper level altostratus were observed to spread many hundreds of kilometres from disturbed regions. Such decks, which often precipitated, were observed to persist longer than should be expected in a generally diverging and subsiding environment. It is argued that the decks were regenerated by radiative destabilization. The effect of a thick stratus deck on the long and short wave radiation fields is to cause substantial heating at the base of the cloud and cooling at the top. The subsequent destabilization and the release of latent heat maintain the deck against evaporation.

### **Paleo-climate**

For reasons indicated in the introduction to this section, a study of the climate of the Australian region during the late Quaternary (about 18000 years ago) has been undertaken. The sea level was then low enough for Australia and New Guinea to be joined by a wide plain, and the continent extended in other regions out to the 200 metre bathymetric contour of the present day. The surface climate of the time, as re-constructed from proxy paleo-ecological evidence, was very different to that of today. For instance, the tropical, sub-tropical and extreme south-east parts of the continent were much drier and the New Guinea highlands were as much as 8°C colder than today.

Having performed this broad reconstruction, the problem was one of establishing the most likely atmospheric circulation which could produce

such a pattern. What was required was a hemispheric long-wave pattern which, among other things, allowed frequent cold outbreak conditions favourable for the maintenance of the New Guinea glaciers. The postulated pattern is considerably different from that of the present day, is consistent with the paleo-reconstruction and, most important, is a dynamically possible situation since similar patterns exist occasionally during present-day anomalous periods. This last point is most significant — namely, that the relation between surface properties and atmospheric dynamics in anomalous present-day situations may be used as a guide to the relation which might have existed more permanently in other times.

### **Southern Hemisphere Climatology.**

Daily analyses of the southern hemisphere atmospheric circulation since the global weather experiment started in January 1979 have been used to obtain statistics for each individual month. These are being compared with climatological charts based on earlier data. A notable difference is the much lower surface pressure in the Antarctic trough in all the months so far studied, and the corresponding higher values for mid-latitude westerlies and polar easterlies. Further preliminary indications are that the eddy kinetic energy of the southern hemisphere general circulation is significantly larger than previously estimated.

### **Radiation — Solar and Thermal.**

The radiation programme deals with aspects of the scattering and absorption of solar and terrestrial radiation within the earth-atmosphere system. Absorption and emission of radiation both at the surface and in the atmosphere leads to sources and sinks of heating in the global system which in turn drive the atmospheric dynamics and determine the global climate. One of the chief modulators of radiation streams in the atmosphere are clouds and their radiative properties have been receiving increasing attention in the last few years. There can be little doubt now that clouds are a dominant control on the overall energy balance of the system and must therefore be accounted for in any realistic model of climate. Incomplete knowledge of the formation, dissipation and radiative properties of clouds has been recognized by the Joint Organizing Committee of the World Meteorological Organization as one major factor limiting the advance of climatic modelling.

This emphasis on clouds has strengthened the already considerable programme of research on radiative properties of clouds which has been an ongoing programme at the Division since the early 1970's. As well as the pure radiative aspects of clouds, the effects of local radiation divergence on the formation and evolution of clouds is also being studied, with particular emphasis at present on tropical cloud systems. Related to the cloud programme are studies on atmospheric aerosols, which also interact with the radiation streams and which may be a factor in climatic change, and on certain surface properties which have a bearing on climate. An important theoretical ingredient in the programme is an evaluation of methods of modelling global climate in terms of the radiation budget of different

latitudes of the world and the resultant global circulation in the atmosphere and ocean. Such studies should ultimately answer questions as to just how the clouds affect the climate, what feedback processes are important, and so on.

The radiation programme includes several other investigations which are of potential or known benefit to the Australian region. These include the measurement of atmospheric turbidity (a measure of the amount of haze or aerosol in the atmosphere) and its effects on solar radiation; monitoring and prediction of ultraviolet radiation reaching the surface, particularly those rays producing sunburn; studies of water vapour anomalies associated with clear air turbulence.

Investigations involving clouds and climate use a considerable amount of satellite data; the radiation programme therefore also deals with the interpretation of satellite cloud signals, with particular emphasis on cloud heights, amounts and radiative properties.

The calibration and standards laboratory continues to provide a service to local industry, and to maintain high quality standards for solar and terrestrial radiation instruments. Further details of this aspect of the Division's work appears at the end of this section.

#### **Theoretical Studies of Climate.**

A purely thermodynamic zonal average climate model based on a constraint of minimum entropy exchange between the earth-atmosphere system and space was reported on earlier. The model has recently been extended to three dimensions and some of the artificial constraints have been removed. This makes possible *a priori* calculations of the broad-scale geographic distribution of cloud, surface temperature, horizontal energy fluxes in the ocean and in the atmosphere, etc. The agreement with observation strongly supports the basic thermodynamic concept. The model should provide a valuable framework for testing the sensitivity of climatic factors to radiative properties of clouds, etc.

#### **Radiative Properties of Clouds — Upper Level Clouds**

Towards the end of 1978 an International Workshop was held at Oxford, England, on the Parameterization of Extended Cloudiness and Radiation for Climate Models. One glaring gap in the knowledge was identified as the radiative properties of high clouds, together with the formation, dissipation and microphysics of these clouds. Much work of an exploratory nature is needed before the problem of parameterization can really be defined. In anticipation of this need, lidar sounding of high clouds was initiated in the early 70's. Since the Division purchased its own lidar in 1975, a more comprehensive and systematic programme has been possible. In 1978, five months of cirrus data were obtained at Aspendale, using both the lidar and the 10-12  $\mu\text{m}$  CSIRO infrared radiometer. Preliminary analysis of these data has shown that the infrared emissivity and the backscatter coefficient at the lidar wavelength have a dependence on ambient temperature (i.e. height). This is the first time that such

dependencies have been detected. The meteorology of cirrus systems will also be investigated in order to try and obtain clues on the mechanism of cirrus formation.

A further project initiated in U.S.A. in 1977, in collaboration with two U.S. institutes, was the simultaneous determination of solar albedo and infrared emissivity using a combination of ground-based lidar scans and data from two geostationary satellites. The results have been compared with theoretical calculations on model clouds. Analysis of the data has highlighted the difficulties involved in deriving high cloud properties from satellite measurements and a more sophisticated analysis has been devised.

A joint cirrus radiation experiment with the New Mexico Institute of Mining and Technology and the US Office of Naval research, was recently made possible by the latter's loan of an unusual type of research aircraft. Able to operate at high altitude and at low speed it was ideally suited from making in-situ measurements of patches of cirrus cloud. Solar and thermal fluxes and cloud particle size distributions were sampled through a number of cirrus clouds. The results established a direct relationship between the ice content of cirrus cloud and the latter's radiation characteristics.

Theoretical work has concentrated on obtaining a model which will predict the optical properties of cirrus to an adequate accuracy. The optical properties of cirrus ice crystals are difficult to represent — there is no known accurate method. However, a model of long ice cylinders appears to be adequate for many purposes, for instance, for predicting the infrared transmittance and possibly the solar reflectance. Apart from being an aid and support to the observational programme the ultimate aims of the work are the parameterization of the optical properties of cirrus for use in dynamical models of the atmosphere and better interpretation of satellite and lidar data in terms of the derived radiative properties.

### **Radiative Forcing in Tropical Clouds.**

Radiative heating associated with tropical cloud distributions, particularly the high cirrus shield, has been shown to be the likely cause of tropical cloud clusters. Therefore this mechanism may have important ramifications for dynamic models of not only tropical disturbances but also the larger scale circulation in the tropics. Another study has shown that cloud amount and type are an important influence on the general atmospheric forcing and thus the effects of radiation and cloud must be accounted for in models of the earth's climate.

### **Remote Sensing.**

*Ice cloud properties.* As well as the lidar projects described above, the extent to which this instrument can be used to obtain information on the microphysics of clouds is being investigated. It is possible now to identify clouds consisting mainly of hexagonal crystals from their characteristic signatures (the crystals float down with their large axes horizontal) and to obtain estimates of the number, density and size of these crystals.

Variations with temperature of the depolarization ratio of the backscattered radiation are also being studied.

***Microwave radiometry.*** Measurements taken at Deniliquin with the CSIRO airborne microwave radiometer in 1976 have been analysed. The analysis shows that the radiometer (operating at a wavelength of 2.65 cm) accurately measures the surface soil moisture content over unvegetated surfaces. The microwave results have been used to obtain a simple parameterization of evaporation from non-saturated surfaces.

***Remote measurement of atmospheric pressure.*** Methods of measuring atmospheric pressure from a satellite have been studied in collaboration with U.S. scientists, in particular a laser technique using the absorption in the naturally occurring oxygen absorption band. Changes in pressure correspond to changes in oxygen mass, and therefore absorption. The general problems associated with the method have been investigated theoretically, and it appears that this approach is feasible. However, high-power laser systems with high wavelength stability are required. The two most promising lasers appear to be a stimulated Raman Scattering (SRS) type and a ruby laser-pumped dye laser. A preliminary experiment at Aspendale indicates that the SRS technique does work, but the efficiency is low. Techniques for obtaining high SRS conversion efficiency and good stability are being investigated in the laboratory. A dye laser is being investigated by workers at NASA, Langley, Virginia, with some initial collaboration from this Division.

***Remote detection of clear-air turbulence.*** American scientists have recently demonstrated that clear-air turbulence can be detected ahead of an aircraft — thus permitting evasive action to be taken. Variations in water vapour emission are detected by a forward-looking radiometer mounted on the aircraft. Associated theoretical studies are being pursued at the Division with the aid of a contract grant from the Environmental Research Laboratories, NOAA, Boulder, Colorado.

### **Ultraviolet Radiation Monitoring Network.**

Radiation measurements of sunburning ultraviolet radiation continue along the east coast of Australia and at Hobart, Port Moresby and Penang. The instruments used are similar to those used in a worldwide network run by the Skin and Cancer Hospital in Philadelphia. Intercomparison between the two networks is possible through duplicate measurements at both Aspendale and Brisbane.

The results from the Australian network have been used to verify a simple atmospheric model which gives the narrow band (290-320 nm) ultraviolet radiation climate of Australia. This model has also been verified against a complex model of solar radiative transfer through the atmosphere.

### **Radiation Standards and Observations**

A second active cavity radiometer has been acquired to augment the group of pyrhelimeters which comprise the regional radiation standard. An electronic data logging system has been developed to allow the two active

cavity radiometers to operate in a semi-automatic mode concurrently with the manually operated Ångström pyrheliometers. The regional standard now consists of the two active cavity radiometers and two Ångström pyrheliometers with two silver disc pyrheliometers in reserve.

Radiation measurements at the Baseline Air Pollution Station, Cape Grim, have now been extended to include diffuse sky radiation. Oversight of the instrumentation and the processing of data from the station continues to be undertaken by the Radiation Group. With the loan of an instrument from the Bureau of Meteorology, atmospheric turbidity measurements by sun photometer have commenced at the Cape.

A regional pyrheliometer comparison was carried out at Aspendale in February/March 1978. The National Standard Pyrheliometers of New Zealand and Indonesia and also that of the Bureau of Meteorology were compared with the Regional Standard. Three clear days of acceptably low turbidity during the period resulted in a comparison of good accuracy.

Twenty-four-hour recording of the main radiation parameters continues at Aspendale: 13 years of good quality data are now available. The measurement of atmospheric turbidity, which commenced in 1968, is also continuing. From the beginning there has been a steady decrease in mean annual turbidity at Aspendale (except for an upward excursion in 1974, which may be related to the Fuego volcanic eruption). These results are consistent with those from the Mauna Loa observatory, Hawaii, although the opposite trend has been observed at some places at high latitudes in the northern hemisphere.

#### IV. ATMOSPHERIC CONSTITUENTS

This programme is concerned 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<sub>2</sub>, through its ability to absorb outgoing longwave radiation may have a warming influence in the lower layers 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 industrialization may increase their concentration and, as well, insert foreign material. This research has implications for climate, for the environment and for health.

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 site for the permanent Australian Baseline Air Pollution Station — are an essential element of this programme),
- (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 the above to possible changes in global climate, to atmospheric pollution and to likely modifications of our environment, especially those which are adverse,
- (4) to utilize some of these constituents as tracers to provide information on the dynamics of the troposphere and stratosphere.

It is important to realize that careful and precise measurement and long-term monitoring is only part of the overall study; interpretation of the data is the essence of the programme.

##### **Carbon Dioxide**

Monitoring of carbon dioxide (CO<sub>2</sub>) background levels in the troposphere and lower stratosphere in the Australasian region has been continued using the Division's aircraft sampling network. Sampling frequency has been reduced in the last two years since we now have a data set which is sufficiently comprehensive for certain aspects of our work, and aircraft availability has changed in some areas. Lower tropospheric flights made in chartered light aircraft have been used to supplement those made by the Department of Transport. In addition, support by Trans-Australia Airlines for the automatic upper tropospheric sampling programme has remained strong. Calibrations of the working gases used during sample analysis at Aspendale and errors due to the carrier-gas effects of the respective infrared gas analysers have been reviewed and six years of high quality data to December 1977 have been published. The accumulated data shows a mean annual increase in background CO<sub>2</sub> of 1.2 ppmv but with a fairly large variability. The standard deviation of these annual increases is 0.6 ppmv.

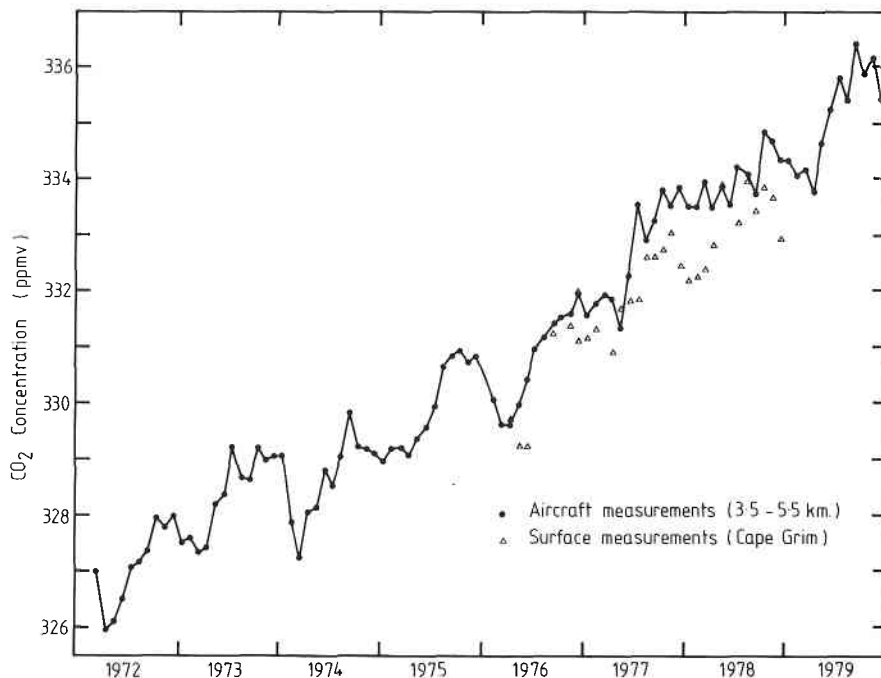


Fig. 2. 'Background' measurements of atmospheric carbon dioxide made at the site of the new (Australian) Baseline Air Pollution Station, Cape Grim, Tasmania, and from an aircraft in the south east Australian region. The similarity between surface and aircraft measurements indicates a well mixed atmosphere in the context of carbon dioxide. It is considered likely that increasing amounts of atmospheric carbon dioxide (whether due to man's burning of fossil fuels or to natural events), could cause a significant change in world climate. One result, among others, would be vast changes in land use patterns including food producing areas.

Preliminary studies of vertical  $\text{CO}_2$  gradients through the troposphere suggest that the oceans are a sink for  $\text{CO}_2$  during much of the year in the south-east Australian region. This proposal is supported by the observation that  $\text{CO}_2$  concentration measurements at Cape Grim are on average  $\sim 0.5$  ppmv lower than those measured at the top of the boundary layer ( $\sim 1-2$  km). Changes in this and other sink strengths possibly account for much of the variability in the annual  $\text{CO}_2$  increases. A detailed study has been made of  $\text{CO}_2$  data from some 400 flights made over the past six years. Using appropriate meteorological data an attempt was made to interpret the similar ( $> 1\%$ ) time and space variations in  $\text{CO}_2$  concentration. It was shown that  $\text{CO}_2$  concentration exhibits marked spatial variations in the tropopause region depending on the prevailing synoptic situation, particularly the position of the jet stream.

Considerable effort has been involved in evaluating and interpreting  $\text{CO}_2$  data obtained from the Australian Baseline Air Pollution Station, run by the Department of Science and the Environment at Cape Grim, Tasmania. The initial object is to establish data selection criteria which can

be used to remove data influenced by local surface exchanges to produce a data set representative of background conditions.

Dr. C.D. Keeling, Scripps Institution of Oceanography, has provided a complete 21 year (1958-1978) daily record of CO<sub>2</sub> concentration from the monitoring station at Mauna Loa, Hawaii. Techniques were developed for removing, from the data set, variability associated with fluctuations and trends which occurred on time scales longer than one year and shorter than 20 days. The resulting data set was used to study year-to-year variation in the annual cycle of CO<sub>2</sub> concentration. The most significant conclusion is that there appears to be evidence of a change in the amplitude of the annual variation throughout the past 20 years, particularly in the last few years. This suggests that net uptake of carbon each year by the non-equatorial northern hemisphere biosphere has increased with time.

Co-operation with the Glaciology Section of the Antarctic Division, Department of Science and the Environment, and the Department of Meteorology, Melbourne University, has enabled a CO<sub>2</sub> measurement programme to be established at the Antarctic station at Mawson (68°S, 63°E) and Macquarie Island (55°S 159°E) in the southern hemisphere temperate westerly wind belt. The Mawson programme entails collection of discrete air samples in glass flasks which are analysed at Aspendale, whilst a semi-automatic gas analysis system is in operation on Macquarie Island. Flask samples of air from the Indian Ocean region are also being collected on our behalf at a coastal station near Perth by the Western Australian Department of Conservation and the Environment.

Commercially available gas analysers used in current monitoring programmes employ a microphonic detection system which is susceptible to mechanical vibration, thus making them unsatisfactory for mobile monitoring systems. To overcome this, a new CO<sub>2</sub> analysis system, utilizing a solid state infrared detector, has been developed in the Division. This instrument performs well under laboratory conditions, and final adjustments are being made so that the instrument can be used in an aircraft.

Experiments are envisaged which require the continuous measurement of CO<sub>2</sub> concentration from moving vehicles or aircraft. These experiments and the data from the Antarctic station will be used in an analysis of the air-sea exchange of CO<sub>2</sub> over the Southern Ocean.

### **Carbon Isotope Studies**

A programme of monitoring the <sup>13</sup>C/<sup>12</sup>C ratio in baseline air from Cape Grim commenced in October 1977. It is hoped that a study of variations in this ratio and a comparison of our results with those from the northern hemisphere will provide direct information on the short term biospheric and oceanic exchange processes and the role of deforestation in the carbon cycle. Refinement of sampling and analysis techniques appears to have overcome initial contamination problems. No trends are apparent at this early stage of the study.

Carbon stored as wood in trees is derived solely from the atmosphere. Since the stable isotope ratios of the wood contain information on the atmospheric isotope ratio at the time of growth, they should then reflect exchanges between the atmosphere and the earth's major carbon reservoirs each of which has a different isotopic label.

This is the reasoning behind the continuing study of stable carbon isotopes in growth rings of Tasmanian trees, an investigation aimed at clarifying major uncertainties in the global carbon budget. The Tasmanian west coast has several unusual features which commend it for this study — remoteness from local and global industry, location in the "roaring forties", a variety of easily dated softwoods with a range of habitat, trees of great age (up to 2000 years), and supporting direct CO<sub>2</sub> measurements at Cape Grim. The results to date from 6 trees, representing a range of species and habitat, show a consistent difference in the post-1900 trend from that identified by northern hemisphere workers who attribute an apparent global trend to fossil fuel combustion and deforestation.

### **Global Dispersion Model**

A two-dimensional computer model has been set up which is designed to simulate the global distribution (latitudinal and vertical) of atmospheric constituents as a function of their source and sink intensity and distribution.

Objectives of the model simulation include the following:

- (1) Modelling the observed amplitude and phase of the atmospheric <sup>12</sup>CO<sub>2</sub> and <sup>13</sup>CO<sub>2</sub> oscillations to infer the biosphere/atmosphere and ocean/atmosphere exchange,
- (2) The use of atmospheric constituents in the study of interhemispheric exchange and response times,
- (3) The interpretation of vertical gradients of atmospheric constituents,
- (4) The study of secular changes in atmospheric constituents and their latitudinal distribution.

The model has been used to simulate the annual variation of atmospheric CO<sub>2</sub> concentrations. Using an iterative process a set of zonally-averaged, monthly, surface CO<sub>2</sub> exchange rates were produced which simulate seasonal CO<sub>2</sub> variations in the model similar to those observed at various measuring locations around the globe. These exchange rates can be interpreted as large scale net photosynthetic rates. It is hoped that the model will also provide a rationale for planning the distribution and frequency of baseline measurements needed to achieve planned objectives.

An investigation is under way to assess the merits of using a Lagrangian rather than a Eulerian climatology in order to make the dynamical simulation as realistic as possible.

## Halocarbons

The monitoring programme for atmospheric halocarbons ( $\text{CCl}_3\text{F}$ ,  $\text{CCl}_4$  and  $\text{CH}_2\text{CCl}_3$ ) has continued successfully throughout 1977-79. Objectives are:

- (1) Compilation of global inventories,
- (2) Comparison of the data from (1) above with known emission sources to calculate atmospheric residence times,
- (3) Utilisation of  $\text{CCl}_3\text{F}$  data to investigate inter-hemispheric exchange ( $\text{CCl}_3\text{F}$  is generated largely in the northern hemisphere).

An aircraft sampling programme covers most of southern Australia including Bass Strait and the Great Australian Bight. Linear regression of  $\text{CCl}_3\text{F}$  concentration with time for the first three years of the programme indicates an increase of approximately  $14\text{-}15 \text{ pptv yr}^{-1}$  (parts per  $10^{12}$  by volume per year), with a mid-1979 concentration approaching 160 pptv. This is identical to both the concentration and trend observed from the first 2.5 years of  $\text{CCl}_3\text{F}$  monitoring data from Cape Grim.

This excellent agreement between aircraft and Cape Grim data shows that, despite the very occasional day of high  $\text{CCl}_3\text{F}$  measurements at Cape Grim, the station is capable of measuring  $\text{CCl}_3\text{F}$  concentrations and trends that are representative of a large region of southern Australia.

It has been shown for a number of days in 1977 that high  $\text{CCl}_3\text{F}$  concentrations at Cape Grim correspond to air masses that had previously passed over the mainland, in particular Melbourne. Later it is hoped to filter out the unrepresentative measurements. There is a suggestion in the  $\text{CCl}_3\text{F}$  monitoring data that the current rate of increase is less than observed when the programme commenced in 1976. This may be related to reduced emissions from the northern hemisphere arising from regulations banning certain uses of chlorofluorocarbons in a number of countries.

In the past it has been found difficult to maintain stable concentrations of  $\text{CCl}_3\text{F}$ ,  $\text{CCl}_4$  and  $\text{CH}_2\text{CCl}_3$  for use as reference gases. New techniques have been developed which overcome the problems and comparisons have been made with calibrated gases from nine overseas laboratories involved in atmospheric halocarbon research. The results suggest that very precise atmospheric halocarbon measurements can be made by different laboratories spread over the globe provided commonly derived and related standards are used.

The results from the halocarbon programme ( $\text{CCl}_3\text{F}$  concentration and trends) have been compared successfully to those predicted by a recently developed box model of the atmosphere.

Based on the 1976 NASA Inter-latitude Survey, an attempt was made to determine the atmospheric residence time of  $\text{CCl}_3\text{F}$  by comparing emissions with global burdens. The calculations suggest a residence time of approximately 40 years, but one as short as 20 or as long as 100 years is possible. In future it is hoped to use the rate of change of the atmospheric  $\text{CCl}_3\text{F}$  concentration to determine this residence time more precisely.

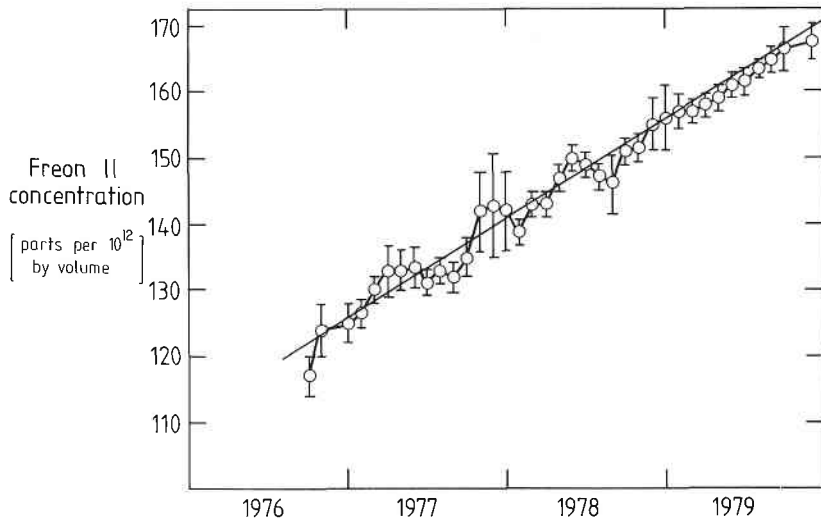


Fig. 3. Surface measurements of Freon II ( $\text{CCl}_3\text{F}$ ) made at Cape Grim, Tasmania, site of the (Australian) Baseline Air Pollution Station. Freon II, widely used as an aerosol and in industry, is entirely man-made. With an estimated atmospheric lifetime of 30 to 50 years, it is possible that chlorine resulting from the eventual breakdown of the freon in the stratosphere may cause a reduction in high level ozone.

In late 1977, routine monitoring of air samples from Antarctica commenced and regular flask monitoring of Indian Ocean air commenced in March 1979. These air sampling programmes involve co-operation between the Meteorology Department, Melbourne University, the Department of Science and the Environment through its Antarctic Division and the Department of Conservation and the Environment, Western Australia. Preliminary results from these two air sampling programmes suggest that  $\text{CCl}_3\text{F}$  is very well mixed latitudinally and longitudinally throughout the southern hemisphere. In general southern hemisphere concentrations are approximately 10% less than those of the northern hemisphere.

In May 1978 a second halocarbon monitoring programme commenced at Cape Grim. This project, run as a joint programme with the Oregon Graduate Centre, is a component of a global experiment designed to describe the occurrence and distribution of  $\text{CCl}_3\text{F}$ ,  $\text{CCl}_2\text{F}_2$ ,  $\text{CH}_3\text{CCl}_3$  and  $\text{CCl}_4$  in the lower atmosphere, with a view to determining the existence or otherwise of atmospheric sinks for these compounds.

Urban measurements of  $\text{CCl}_3\text{F}$  have continued on a limited basis with the objective of correlating urban levels observed at Aspendale, with air pollution potential.

The vertical structure of the  $\text{CCl}_3\text{F}$  plume from Melbourne has been investigated by vertical profiling of air samples taken over Bass Strait on days with suitable synoptic conditions. Attempts to detail the horizontal structure of this plume have not been successful so far.

Current  $\text{CCl}_4$  concentrations observed at Cape Grim are approximately 140 pptv, with an annual increase of approximately 1 pptv. These values are consistent with those calculated by a global  $\text{CCl}_4$  inventory model developed in this Division.

A preliminary investigation of stratospheric humidities in relation to air trajectories has not shown any significant correlation. Further flights have been undertaken as part of the joint atmospheric CSIRO/Environment Service, Canada/York University stratospheric experiment.

## **Ozone**

### **In the stratosphere**

The ozone layer plays a key role in the ecology of the earth. Current predictions of ozone depletion based on the 1977 concentration of chlorofluoromethanes, indicate a photochemical depletion of ozone of about 15% in about 20 years time. This is approximately one and a half times larger than a prediction made only a year ago.

The study of the ozone layer involves the understanding of the chemical and dynamical processes in the stratosphere and, more importantly, careful monitoring of the ozone layer itself. The observing programs using Dobson spectrophotometers have continued at Cairns, Brisbane, Aspendale, Hobart, Perth and Macquarie Island. The fortnightly determinations of the vertical distribution of ozone by balloon-borne chemical sensors (Mast-Brewer sondes) has also been continued.

Modification, calibration and intercomparisons of Dobson spectrophotometers have occupied much of the time during the past three years. In August 1977, Australian standard Dobson spectrophotometer (No. 105) which is designated the standard for the W.M.O. Region V (South-West Pacific) was transferred to Boulder, Colorado for comparison with the primary instrument (No. 83 — World Standard) belonging to the USA. The intercomparison was organised and supported financially, by the WMO. At this comparison, seven national standards were calibrated against the primary. In February 1978 the New Zealand instrument was brought to Aspendale and compared with our regional standard (No. 105). In January-February 1979, the Division provided assistance to the Thai Meteorological Department to calibrate and set up a Dobson spectrophotometer at Bangkok. This instrument was brought to Aspendale in October 1979 for updating the electronics, calibrating and comparing against the Australian standard. Two officers of the Thai Meteorological Department were trained in the observational techniques.

Analysis of long term trends in ozone in the stratosphere — obtained by ozone sonde flights at Aspendale — shows an ozone decrease in the 100-20 mb region during the 1965-78 period. This is consistent with an approximate (measured) 4% decrease in total ozone at Aspendale between 1957-1977. Further analysis of winds, temperature and the vertical distribution of ozone obtained by umkehr observations shows that the decrease is the result of the weakening of the stratospheric circulation

and is not due to the injection of man-made material into the stratosphere.

The long series of total ozone data (obtained by the Standard 'AD' method) is found to correlate inversely with the aerosol scattering obtained from observations using a Dobson spectrophotometer. This indicates that the long term trend in ozone is influenced by secular changes in the scattering — an aspect not taken into account in the day-to-day calculation of ozone. The previous estimate that about 50% of the total trend may have been due to changes in the scattering properties of haze and dust appears reasonable.

In connection with the biennial oscillation, a study has been carried out comparing the average ozone maxima of alternate years. It has been found that — averaged over a number of years — the difference between ozone maxima of one set of years and that of the alternate years became apparent earlier in low latitudes than in higher ones e.g. February in Darwin and Cairns, April in Brisbane, June in Aspendale and August in Macquarie Island. The investigation of the interaction between the biennial oscillation in stratospheric winds and the movement of the ozone oscillation towards higher latitudes is continuing. Since the minimum ozone remains the same in all years, it is obvious that the destruction of ozone is also a two yearly phenomenon even in mid-latitudes.

### **Near the Surface**

Ozone in the background atmosphere under baseline conditions can come from two sources: stratospheric ozone-rich air passing down into the troposphere, and local photochemical production processes in the unpolluted lower atmosphere. Ozone along with nitrogen oxides dominate the chemistry of the lower atmosphere, regulating the rate of oxidation of nearly all substances in the troposphere. This ozone is subsequently destroyed at the underlying surfaces and by chemical processes within the air. The concentration of ozone in the surface air and its short and long term variations reflect changes in the production and removal mechanisms. Long term monitoring of the surface ozone concentration therefore reveals information about a number of complex mechanisms present in the atmosphere.

Surface ozone is monitored continuously at Macquarie Island and at the Cape Grim baseline station, Tasmania. These stations have relatively clear air so that measurements can be regarded as background levels. The data for Cape Grim for 1977 show a minimum average ozone concentration for baseline conditions of about 17 ppb in the summer months and a maximum ozone concentration in the winter and spring months reaching 30 ppb in August.

This maximum ozone concentration in the winter/spring months is consistent with injection of ozone from the stratosphere causing a build up in the tropospheric ozone concentration. Observational evidence from vertical ozone profiles and radioactivity in surface air of stratospheric origin, suggests that the major stratospheric/tropospheric exchange occurs in late winter and spring. The low ozone concentration during the summer months

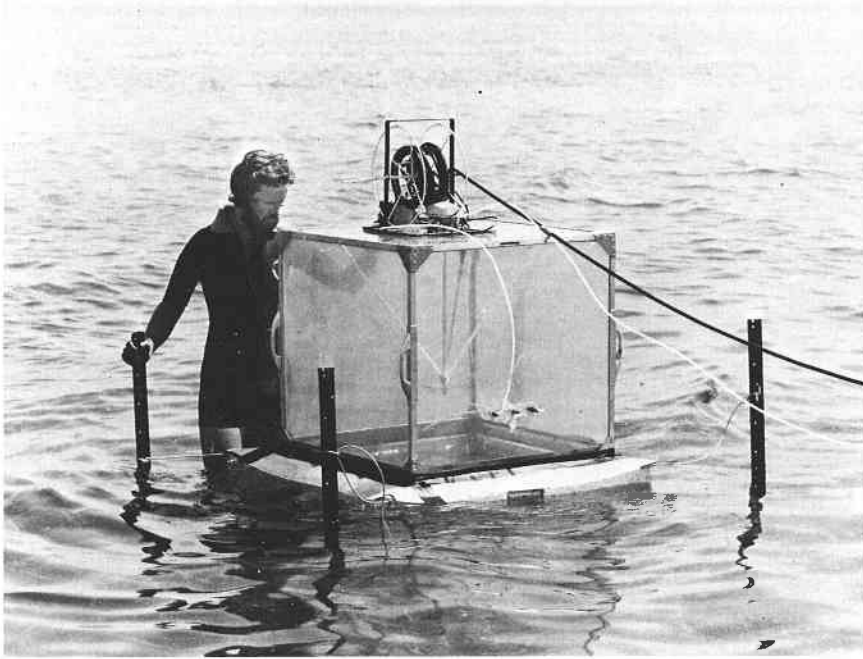


Fig. 4.  
Measuring the destruction of ozone over the sea. A considerable proportion of the ozone in the troposphere is destroyed at ground level, the rate depending, amongst other factors, on the nature of the underlying surface. This investigation is part of a general study aimed at understanding sources and sinks of ozone in the earth/atmosphere system.

when solar radiation is most intense suggests that photochemical production of ozone in the background atmosphere is of secondary importance compared with stratospheric injection as a source of tropospheric ozone. Further analysis is under way.

The destruction rate of ozone on various natural surfaces, e.g. soil, vegetation and water, has been studied using ozone decay methods. An interesting discovery is that surface resistance to ozone uptake (which is inversely proportional to the ozone destruction rate at the surface) increases at night, i.e. for a fixed ozone concentration in surface air, there is less ozone destruction at night than during daytime. It is thought that factors such as the closing of plant stomata — which prevents ozone molecules passing into, and being destroyed within the plants — and any increase of surface soil moisture at night may cause this decrease in ozone destruction rate.

A representative global ozone destruction rate for the earth's surface is derived using the above information. Allowance is made for the latitudinal variation of the different types of surface, their various ozone destruction

constants, the latitudinal and diurnal variation of ozone in the surface air and the diurnal variation of eddy transfer near the earth's surface. The global average ozone destruction rate is estimated to be  $4 \pm 2 \times 10^{29}$  molecules  $s^{-1}$  ( $1 \pm 0.5 \times 10^{12}$  kg  $yr^{-1}$ ). This range extends to slightly higher values than previous estimates. About 40% of this destruction takes place in the southern hemisphere and the balance in the northern hemisphere. Thus the net source of ozone in the northern hemisphere appears to be only slightly larger than that in the southern hemisphere, contrary to recently published estimates.

During 1978, the ozone standard used for these studies was part of the National Intercomparison of Ozone Standards conducted by the Department of Science and the Environment.

## **Oxides of Nitrogen**

### **Nitric Oxide (NO) and Nitrogen Dioxide (NO<sub>2</sub>)**

These compounds are collectively referred to as NO<sub>x</sub>. Tropospheric NO<sub>x</sub> is generated mainly by bacterial and chemical reduction of nitrogenous compounds in the soil, the remainder being attributed to anthropogenic sources, primarily high-temperature combustion processes (e.g. in automobiles, and power plants). NO<sub>x</sub> directly affects ambient ozone and hydroxyl radical concentrations which in turn predominantly determine the rate at which oxidation processes occur in the atmosphere. Also, these nitrogen oxides are precursors for nitrate compounds in atmospheric particulates and nitrate ions in rainwater.

To help study natural and anthropogenic sources of these oxides and to detect any local and/or global trends, a chemiluminescent detector specific for NO<sub>x</sub> has been designed. Built in the Division, it has been installed at Cape Grim and will provide a continuous measurement of nitrogen oxides in clean surface air.

For the first time, emissions of NO and NO<sub>x</sub> from various soil surfaces have been measured. These emissions appear to result from the decomposition of trace amounts of nitrite within the soils. The loss of NO may not be a permanent loss of fixed nitrogen as this nitrogen is most probably returned to the soil as nitrates in rainwater. Thus NO exhalation may be a significant process in redistributing fixed nitrogen throughout the global biosphere.

In the southern hemisphere the anthropogenic fixed odd nitrogen, (NO<sub>x</sub>), source from combustion is about  $1$  to  $2 \times 10^9$  kg nitrogen  $yr^{-1}$  whereas the source from soil is probably  $3$ - $4 \times 10^9$  kg  $yr^{-1}$ . These sources of NO<sub>x</sub> are balanced by uptake of gaseous NO<sub>x</sub> at the surface and the nitrate deposited in rain and snow. Estimates of the amount of nitrate nitrogen so deposited, for the hemisphere, based on observations in Antarctica and Tasmania, suggest annual deposition of the order of  $2$  to  $4 \times 10^9$  kg nitrogen  $yr^{-1}$ .

Incidentally, the emissions reported here are, per unit area, about forty times larger than the depositions of NO<sub>3</sub> nitrogen reported for Antarctic ice. We suggest this NO<sub>3</sub> nitrogen in Antarctic ice may result from the long

range transport of fixed nitrogen from the continental regions of the southern hemisphere.

A preliminary examination of the nitrogen cycle in a grazed pasture — which had not received nitrogen fertiliser over the past 8 years — has been made by this Division and those of Plant Industry and Environmental Mechanics. Rates of exchange between the soil and the atmosphere of  $N_2$ ,  $N_2O$ ,  $NH_3$ ,  $NO$  and  $NO_2$  were measured, along with many soil and atmospheric parameters. The data are being analysed.

### **Nitrous Oxide ( $N_2O$ )**

$N_2O$  is a ubiquitous constituent of the earth's atmosphere. It is predominantly of natural origin being produced by microbiological reduction of fixed nitrogen at the earth's surface. In the stratosphere,  $N_2O$  is oxidized to nitric oxide — a substance thought to play a significant role in the chemical control of stratospheric ozone ( $O_3$ ). There has been recent concern that man's activities may increase the production of  $N_2O$  which could upset the balance of stratospheric  $O_3$ .

Measurement of atmospheric  $N_2O$  commenced in late 1976. Results from an extensive gas sampling network covering Australia, the Southern Ocean and the Tasman Sea show that  $N_2O$  is homogeneously distributed throughout the troposphere in space and time. Unlike earlier  $N_2O$  observations in the northern hemisphere, where average annual concentrations have shown a 20% variability, Aspendale data is conspicuous for its lack of variation ( $<1\% \text{ yr}^{-1}$ ) indicative of a long atmospheric lifetime. It is now believed that the variability shown in northern hemisphere results stem from the earlier, relatively insensitive measurement techniques then in use.

The  $N_2O$  concentration is found to decrease with altitude in the stratosphere as would be expected of a compound with a stratospheric sink. An important finding of this study is that the atmospheric lifetime of  $N_2O$  (probably  $> 28$  years) is considerably longer than originally thought (1-2 years). This implies smaller source and sink strengths and makes the atmospheric  $N_2O$  cycle more susceptible to anthropogenic inputs.

The loss of  $N_2O$  from soils was investigated during the field experiment mentioned earlier in this section. Although preliminary results only are available to date, it has been found that in general the  $N_2O$  flux increases with nitrate concentration and soil temperature. However, there is considerable variation in  $N_2O$  fluxes (almost a factor of 50) at different sites in the field.

### **Stratospheric Nitrogen Oxides Experiment**

The Australian Academy of Science Committees concerned with "Atmospheric Effects of Supersonic Aircraft" and "Climate Change", and the World Meteorological Organization (WMO), have recognised the potentially harmful effects of nitrogen oxides and chlorofluoromethanes in reducing the quantity of ozone in the stratosphere and have recommended a direct monitoring programme for nitrogen oxides in the stratosphere.

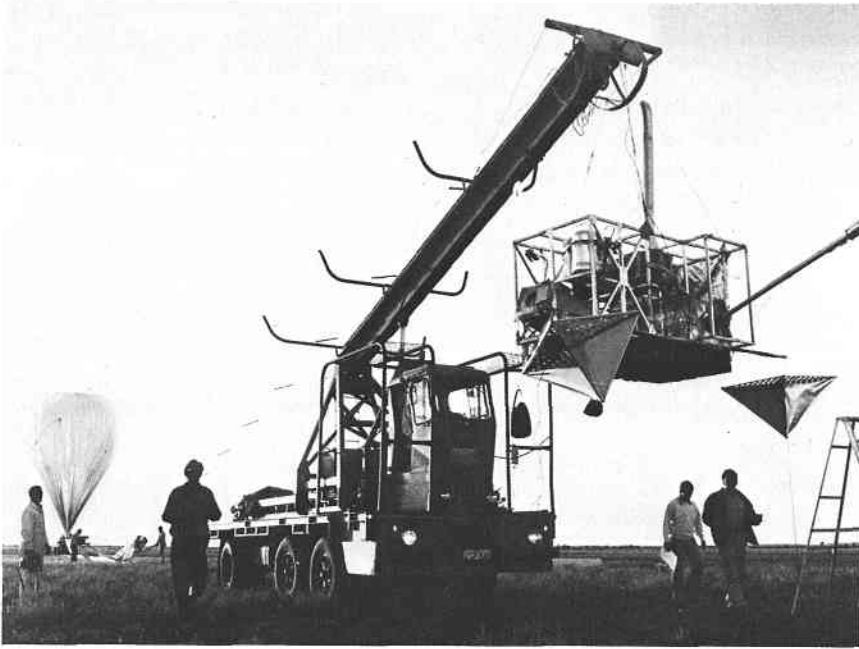


Fig. 5.

Preparing a flight at Alice Springs — part of the stratospheric nitrogen oxides experiment. A joint effort with York University and the Atmospheric Environment Service, Canada, the aim is to measure (for the first time) the vertical distribution of nitrogen oxides in the southern hemisphere. The payload which can be seen suspended from the launching vehicle, is carried aloft by a helium-filled balloon. The measurements are radioed back to earth and when completed the equipment is cut away by remote control, returning to earth on a parachute. The descent is followed by radar (the two triangular shaped objects underneath the equipment are radar reflectors), and by aircraft. This work receives financial support from the U.S. Federal Aviation Agency.

In December 1977 a joint venture with York University, Canada, commenced with two balloon flights at Mildura making the first measurements of vertical profiles of nitric oxide in the southern hemisphere stratosphere. The concentrations observed are very similar to those measured at Texas, U.S.A., in similar conditions, suggesting that the stratospheric nitric oxide distribution may, at low latitudes, be symmetric through the two hemispheres. This nitric oxide data along with nitric acid data collected at Mildura during 1971-1973 has been compared with physical-chemical stratospheric model results. Some substantial discrepancies are evident.

Following the successful flights referred to above, a comprehensive programme for the measurement of nitrogen oxides in the southern hemisphere stratosphere started in March 1979. The purpose is to compare observations with theoretical models used to predict the effects of possible man-made influences on the ozone layer. The one-year programme involved eleven stratospheric balloon flights to measure  $N_2O$ ,  $NO$ ,  $NO_2$  and nitric acid, together with  $O_3$ , water vapour, and

chlorofluoromethanes. Some of these measurements are the first to be made in the southern hemisphere. Flights were made from Mildura and Alice Springs during the autumn and Mildura in spring. Scientists from York University and the Atmospheric Environment Service, Canada, are taking part. Financial support is provided by the U.S. Federal Aviation Agency. Analysis of the data is under way.

### **Photochemical Smog in Melbourne**

Photochemical smog results from the interaction of various atmospheric pollutants under the influence of sunlight, giving rise to concentrations of ozone which are harmful to the health of humans.

The increasing problem of smog in Melbourne is largely attributable to the exhaust emissions from motor vehicles. Although a start has been made to limit such emissions in accordance with the Australian Design Rule, ADR 27A, there is no information available to allow an estimate to be made of the reduction in photochemical ozone which might be expected from a given reduction in emission.

The present programme has therefore been undertaken to determine, by smog chamber techniques, the relationship between the concentration of precursors and the resultant concentration of ozone. It is intended that the results shall have direct application to the Melbourne situation. The smog chamber therefore will be charged with a sample of the Melbourne atmosphere, and the operating conditions of the chamber (namely the initial concentrations and the temperature, radiation and dilution profiles) will simulate typical Melbourne smog events.

To determine the required profiles, a survey of the Melbourne smog situation has been undertaken by means of an aircraft equipped to measure the required chemical and meteorological parameters.

Flights which began in the summer of 1978-79 established that the 7-9 AM emissions from the central business district (CBD) constitute by far the most prolific source of photochemical precursors and that the trajectory of this CBD parcel determines where the serious concentrations of ozone are to be found. Attempts to estimate this trajectory from wind measurements at fixed meteorological stations have proved futile, but by releasing pilot balloons from a mobile station which follows the CBD parcel, the position of the parcel can be accurately determined.

Using this information the aircraft follows the CBD parcel measuring the changes in concentration of nitrogen oxides, hydrocarbons, and ozone. The overall dilution profile is determined by measurements of the concentration of unreactive components in the parcel such as acetylene or carbon monoxide.

The results demonstrate strikingly how seldom the parcel of high ozone concentration is situated over suburban Melbourne.

### **Stratospheric Water Vapour**

Water vapour plays a major role in the chemistry of the stratosphere. Indeed, recent chemical, kinetic and stratospheric modelling studies have shown that stratospheric hydrogen radicals, which originate from stratospheric water vapour, dominate all other ozone loss mechanisms throughout most of the stratosphere. Southern hemisphere data are essential to study source/sink relationships for stratospheric water vapour and to determine long term global trends. The Division has been monitoring such water vapour since 1973. From mid-1977 to mid-1979 a further 11 successful balloon flights were organised.

### **Particulates**

The surface air sampling network, which has been operated for six years along the east Australian coast and at one location in Papua New Guinea, was closed down in September, 1977. Analysis of the filter samples, to determine the concentrations of various metals and thus infer the sources of the particles, is proceeding. High volume sampling at Aspendale, where particulate concentrations in near-surface air have been measured since 1966, is continuing. No long term trends are apparent in the total particulate concentrations.

A heavy duty air sampler was operated at the Baseline Station at Cape Grim during August to December 1976. A mean value of  $18.6 \mu\text{g}/\text{m}^3$  was found for the total particulate concentration during baseline conditions. Analysis of the collected particulates by atomic absorption spectroscopy showed that up to 30% of the total loading during baseline conditions was due to the sea salt component. Concentrations of 12 individual metals were measured and were generally of the same order of magnitude as concentrations of those metals which have been measured over the Indian Ocean in the southern hemisphere from Soviet weather ships. The high volume sampler was re-installed at Cape Grim in January 1978 and a longer term study of atmospheric particulates in southern hemisphere mid-latitude background air is now under way.

## **V. METEOROLOGY**

It is not widely appreciated that whilst the sun provides the energy on which the world's weather systems depend, transformation from solar radiant energy to atmospheric kinetic or potential energy begins at the earth's surface. Initially, it is by conduction, where the warmed underlying surface heats the layers of air immediately above it, and through evaporation (where the dispersing water vapour carries with it latent heat). The amount of energy so transferred depends on the nature and temperature of the surface. The subsequent distribution of energy throughout the atmosphere is then achieved by turbulence, whether mechanical — as generated for example by air flowing over mountains — or convective as in the case of thermals. In both cases, the extent to which energy is distributed vertically depends, to a marked degree, on the atmosphere's stability.

The early work of the Division was devoted in large part to micrometeorology i.e. the exchange of heat, water vapour and momentum between the atmosphere and the underlying surface (both land and sea). This involved a number of extensive field experiments to accumulate the 'real atmosphere' data needed to corroborate — or otherwise — the theories which were being developed in parallel. It also included the design and fabrication of instruments to make the relevant measurements. The knowledge accruing from these investigations has been utilized and extended over the years to study phenomena extending from the meso-scale, (e.g. sea breezes), through the synoptic-scale, (e.g. fronts), to global-scale events (e.g. the monsoon systems).

One of the newer initiatives emerging is the burgeoning Cold Front Research Program — formulated to study the structure of frontal systems in terms of their evolution, dynamics and thermodynamics, and interaction with the underlying surface. Despite the advances in techniques used to forecast the weather, the common cold front still poses major questions which need an answer if there is to be an improvement in forecasting. The exercise is a joint one with University Departments, the Bureau of Meteorology, and the CSIRO Division of Cloud Physics, the initial emphasis being on field studies since there is a dearth of suitable observations.

As in the past our philosophy is still that of tackling fundamental issues first, so ensuring that all new work rests on a sound basis adequately supported by observation and theory. The ultimate objective also remains unchanged, namely the application of results to problems of national and economic importance. One such, is an extended study of the climate of Victoria's Latrobe Valley — a growth area for industry.

### **Air-Surface Interaction**

In the last two years, work has concentrated on aspects of the convectively unstable boundary layer over the land, both close to the surface and throughout the boundary layer as a whole. Essentially the approach has been to confirm and extend theoretical and semi-empirical



Fig. 6. Launching one of the southern hemisphere's 300 drifting buoys in the International GARP Experiment. Moving with the ocean currents, the buoys measure sea-surface temperature and pressure. The information is transmitted by radio to Toulouse, France, via the Tiros-N and NOAA-6 satellites which also fix the buoys' position at regular intervals. The buoys move in a generally easterly direction and typically have useful life spans of a year plus before the batteries expire.

treatments as applied to the real atmosphere, based on analysis and interpretation of data obtained from recent field experiments. Lately this work has been extended to cover the nocturnal boundary layer.

#### **Atmospheric Boundary Layer.**

Field data from three earlier, major field experiments, (Wangara, 1967; Koorin, 1974; Amtex, 1974/5) have been used to describe the bulk characteristics of heat transfer for the unstable, baroclinic boundary layer, over land and over the sea. The combined data support a formulation relating surface heat flux to the temperature drop across the layer in terms of, (a) effective surface temperature, (b) a height scale equal to the depth of

the convective, mixed layer itself, (c) a function of stability. No significant effect of baroclinity was found, although under baroclinic conditions, residual variance in the stability function referred to in (c) is marginally reduced when area-averaged quantities are used rather than single-point values.

Amtex wind data were used to investigate the stress-wind relation over the sea in highly baroclinic conditions; again a realistic interpretation required use of area-averaged wind profiles. Vertically-averaging real and geostrophic winds in the mixed layer improved their correlation with surface stress, mainly by minimising the effects of baroclinity upon winds at specific localities and heights. The boundary layer drag coefficients thus inferred do not differ significantly from previously published values, generally for less extreme conditions.

### **Atmospheric Surface Layer.**

*Over the sea.* Comprehensive eddy correlation measurements of turbulent fluxes during Amtex (the international experiment of 1974/75 over the East China Sea) provide strong evidence for a wind speed dependence of both drag and heat transfer coefficients, with little effect seen in the water vapour coefficient. The drag result is consistent with a recent study for the ocean but that for heat is totally unexpected. No satisfactory explanation emerges from a search for possible systematic errors in instrumentation, for errors in sampling or for the effects of a coral reef. To explain the differences between sensible and latent heat coefficients either four independent heat flux measurements are equally in error for an, as yet, unknown reason, or a preferential enhancement of sensible heat flux in conditions of spray must be invoked.

*Over forest.* Flux-profile analysis of the Koorin observations, taken over an irregular open forest, reveals an apparent lower height limit to the applicability of the conventional Monin-Obukhov stability relationship, and by implication to that of the logarithmic wind law in neutral conditions. The limiting height, approximately equal to three times the mean tree spacing, represents the top of a near-surface transition layer in which vertical gradients are reduced, presumably due to increased eddy diffusivities, themselves arising from extra turbulence from the wakes of individual trees.

Within this layer, the profiles depend on an additional "wake-strength" function,  $\phi(z/z_s)$ , given by the ratio of the observed vertical gradient to that expected from conventional theory, where  $z$  is the actual height above ground and  $z_s$  is a length scale characterising the particular surface geometry. The data show  $z_s$  to be approximately the depth of the transition layer itself, while  $\phi$  is found to vary approximately exponentially between unity at the layer top and about 0.5 at the surface — for both wind and temperature profiles.

## International Turbulence Comparison Experiment (ITCE) 1976.

In 1976 the Division organized an extensive international field experiment at Conargo, New South Wales, the principal objective of which was a detailed investigation of the performance of sensors measuring horizontal and vertical wind speed, temperature and humidity. The experiment was divided into two parts — main core and micrometeorological.

(i) **Central Core Experiment.** The spectral analysis of all data has now been completed and a thorough scrutiny of the data made for the correction of errors and the deletion of data where an instrument malfunction occurred.

Analysis of the data has concentrated on the middle section of the spectrum for a comparison of calibration performance. U-sensors (horizontal wind velocity) and T-sensors (temperature) showed agreement to within a few percent. W-sensors (vertical wind velocity) also showed agreement to within a few percent for most sensors, but propellor anemometers revealed a loss of high-frequency response which penetrated the middle spectrum slice. Q-sensors (humidity) showed considerable variability. Lyman- $\alpha$  hygrometers appeared to show some calibration differences, and wet and dry bulb psychrometers used by some participants showed significant lapses at higher frequencies. Infra-red hygrometers showed the best agreement and their design and calibration have been further improved following ITCE.

In general, eddy flux measurements showed poorer agreement than variance measurements themselves. This is believed to be due to spatial separation for some of the sensible and latent heat fluxes, and to distortion of the flow, with a corresponding need for a tilt correction in the case of the momentum flux.

For comparison purposes, the technique adopted was to select well researched instruments as reference standards against which all others were compared. In addition the reference standard for humidity flux was compared with lysimeter data, that for momentum flux with drag plate data, and that for sensible heat flux with a separate Fluxatron instrument, which itself had been verified by an energy balance.

The overall impression received was that satisfactory eddy flux measurements can only be made if attention is paid to high frequency response, distortion of flow by supporting structures and horizontal separation of sensors; and a careful watch kept to detect instrument malfunction.

A technical report giving full details of the experiment and analyses is nearly completed.

(ii) **Micrometeorological Experiment.** As an adjunct to the central core experiment, profiles of wind, temperature and humidity were taken together with appropriate radiation and ground flux data. The number of independent measurements of both surface fluxes and profiles at the

uniform site of ITCE provide a unique opportunity to assess the influence of technique in the determination of flux-profile relationships.

Analyses of momentum and heat data have identified instrument influences and the effect of these on the generalised profile parameters has been quantified. The possibility of overspeeding of cup anemometers has been a controversial subject in recent literature. Detailed comparisons between an ITCE 6-cup anemometer and a sonic anemometer show a difference which is dependent on the standard deviation of wind direction and reflects the fact that the cups respond to the total wind,  $(u^2+v^2)^{1/2}$ , rather than to  $u$  alone. The combined effect of other possible sources of overspeeding appears to be less than a few percent.

A technical report on the micrometeorological experiment has been completed.

### **Sundry Developments.**

The final developmental model of an Energy Partition Evaporation Recorder (EPER), of a design evolved by this Division over the last decade or so, has completed very successful comparative trials against one of the Aspendale weighed lysimeters. As a result, nine EPER units are about to be built, for use mainly in irrigation water-use studies, by various State and University departments in the fields of agriculture, botany and water supply.

### **Regional Meteorology**

This aspect of the Division's work deals with the 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.

### **Latrobe Valley and Associated Projects.**

The Latrobe Valley is becoming rapidly industrialized and the Division is already well into a long term study aimed at determining the likely impact of a proposed 4000 MW electricity generating station on the climate and environment of the Valley. A number of separate but inter-related topics are being investigated using the Valley essentially as a large field laboratory.

**Plume rise statistics.** In a joint exercise with the SEC of Victoria, radio-sonde observations have been made over the past two years in the Latrobe Valley and the data processed. From it has emerged information on the rise and dispersion of plumes from chimneys and cooling-towers, for a wide range of chimney heights and heat emission rates likely to be encountered in the Valley. The statistics demonstrate the influence of various engineering design parameters, and facilitate quantification of cost-benefit options in improving atmospheric dispersal of pollutants.



Fig. 7

The Latrobe Valley, Victoria, is a growing industrial area and the Division is engaged in a long-term study aimed at determining the impact of a 4000 MW electricity generating station on the local climate and environment.

In view of the anticipated value of a wider coverage for statistics of this kind, an Australia-wide analysis has commenced. This has called for a reprocessing of original radiosonde soundings made by the Bureau of Meteorology. So far, 1973-77 data have been processed for Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Williamstown-Sydney. This major survey of the control of plume-rise by meso-scale climate will be complete by the end of 1980.

**Katabatic flow.** At night time the near-surface layers of the air are cooled generating a katabatic (down-slope) wind. This can occur on quite gentle slopes and results in a body of cooled air collecting at the lowest point — in this case the Valley floor. The result is a stable stratification in the lower atmosphere which tends to trap any airborne pollutants. Because the details of katabatic flow are still imperfectly understood, observations of this phenomena are continuing in the Callignee Valley, a 5 km tributary of the Latrobe Valley.

An improved design of tethered-balloon sonde has been developed. Winched repeatedly up and down between the surface and 200 m height, up to 3 profiles can be obtained simultaneously at different points along the

slope. This is augmented by a central, comprehensively instrumented 30 m mast providing surface fluxes and accurate near-surface profiles.

Detailed examination of the data has shown the inadequacy of existing simple but widely used models. In particular, the observed volume fluxes would call for unrealistic assumptions about the surface sensible heat flux and/or the radiation divergence up to 100 m or so. Earlier indications have confirmed that the most important retarding force is not friction at the surface, which is effectively decoupled from the flow by strong near-surface stability, but rather the mutual entrainment drag at the interface between the top of the flow and the overlying ambient wind when outgoing long wave radiation from the earth's surface causes its temperature to drop.

***Valley circulations in a crosswind.*** Numerical and laboratory experiments have been carried out to determine the conditions under which stagnant air trapped in a valley can be swept out by a cross-wind. In the laboratory, use was made of a simple model of a valley towed through a tank containing appropriately stratified fluid. In addition, two different kinds of numerical model have been run on computers. In each case, the results showed that a simple Froude number criterion based on the strength of the stratification, the depth of the valley and the speed of the cross-wind, could be used to determine the degree of removal of stagnant air.

***Wind Direction Fluctuations and Crosswind Dispersion.*** Eulerian observations of wind direction fluctuations in slightly unstable conditions have been analyzed in terms of Taylor's statistical theory of dispersion, together with the Hay-Pasquill assumption of similar shapes for Lagrangian and Eulerian spectra. The purpose is to test various relations describing the increase in crosswind dispersion of material with distance downwind from a source. These data show much less scatter than direct dispersion observations, and can thus be used to distinguish more clearly between dispersion relations. The data support an empirical form recently proposed to fit observed crosswind dispersion.

The consistency of this relation in representing both the Eulerian measurements and direct Lagrangian dispersion observation serves to support not only the relation itself, but also, indirectly, the Hay-Pasquill hypothesis. Evidence of a correlation between the intensity and scale of turbulence was also found. A proposed continuing analysis over a larger range of atmospheric stability conditions aims to confirm this relation which should prove useful for estimating dispersion from wind statistics.

***Regional influence on meso-scale low level air motion.*** A study was made of the meso-scale controls of atmospheric dispersion preceding and during known days of high oxidant pollution in Melbourne. This detected the previously unknown night time influence of large eddies that form over the central regions of Victoria in the wake of the Australian Alps. These flows are characterised by low Froude numbers, i.e. they have insufficient kinetic energy to flow over the alps and instead are deflected around them. Similar flows have been successfully reproduced in the laboratory by towing topographic models through a tank of saline water stratified to

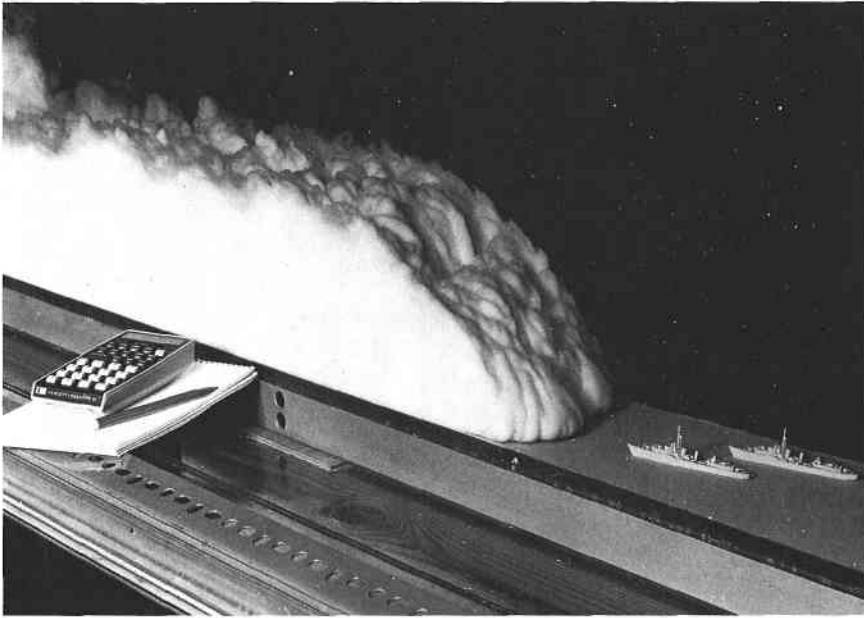


Fig. 8.

The Southerly Buster. Top, a model of the Southerly Buster created in the laboratory using a tank of density stratified saline water to represent the atmosphere. Below, a picture of a real Southerly Buster — the winning entry to a public competition organised by the Division for the best picture of this phenomenon. Well known on the south coast of New South Wales, the Buster is associated with the passage of a front and can be recognised by its typical roll-cloud formation and an abrupt change in wind direction and drop in temperature.

simulate the atmospheric Froude number. This work is continuing and will be extended also to the Adelaide region where similar influences are suspected.

### **Surface Drift**

Studies of the surface layers of large enclosed bodies of water, and the influence of wind on the drift of oil, have been concluded. Two reports have been prepared — one on Westernport Bay and one on the influence of water depth on surface drift.

A critical review of the physics of self-spreading oil on water was provided for the "Victorian State Plan to Combat Pollution of the Sea by Oil". The main findings were then combined with those on drift to provide a method for selecting operational strategies, to deal with a major spill in Port Phillip Bay.

### **The Southerly Buster**

A theoretical model for the "Southerly Buster" has been further developed and compared with observations, with satisfactory results. The phenomenon is seen as the dynamical adjustment of a moving cold front as it encounters a mountain range (the Australian Divide), thereby forming a coastal jet.

### **Tropical Meteorology**

For various reasons, tropical meteorology, especially that of the Australasian region, has long been neglected. However a start has recently been made to expand our work in this area.

Australia lies to the south of the tropical complex of Indonesia and the great continent of Asia. Straddling the Tropic of Capricorn, some 40% of the Australian land mass lies within the tropics. Its climate and weather is interwoven with the largest and most vigorous atmospheric circulation on earth — the Asian/Australasian monsoon. As a result, the meteorology of the entire Australian continent is affected on time scales varying from daily to seasonal by events which have their origins in both high and low latitudes.

Despite their importance, the tropical regions have been poorly monitored in the past and there is a great lack of good surface-based observations. The result is ineffective forecasting at low latitudes and slow evolution of the theory of tropical phenomena. Currently there is a pressing need to develop a means of forecasting the birth and growth of individual tropical cyclones and equatorial disturbances as well as years of abnormally high or low tropical cyclone incidence. Equally necessary is an ability to forecast the 'active-break' sub-seasonal cycle of monsoon activity which defines the major variations of rainfall in the established monsoon. To achieve these ends we need a greatly improved knowledge of low latitude processes themselves as well as an understanding of the interhemispheric coupling mechanism of monsoon circulations.

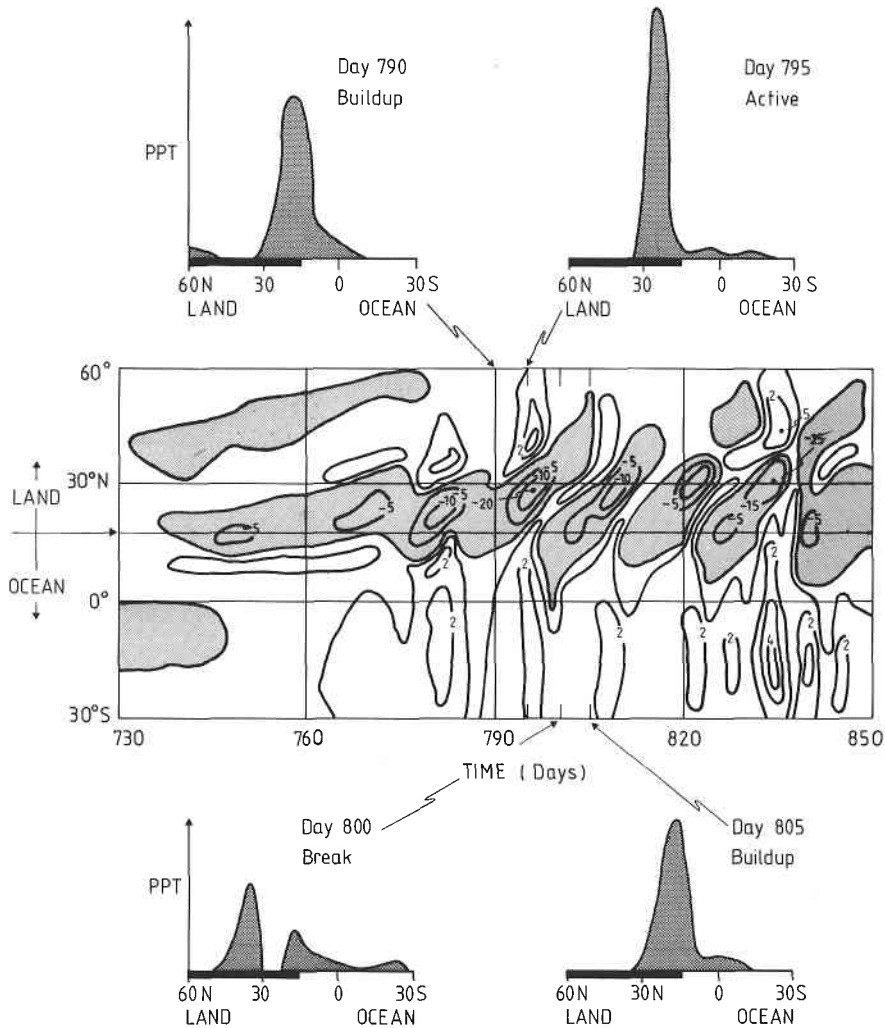


Fig. 9. An example of a model simulation of the Asian monsoon. The shaded area denotes rising motion which may be seen as long period (of the order of 15-day) variations. Such variations arise from the northward migration of the 'monsoon cell' across the ocean/continental boundary. One such sequence is highlighted and the precipitation plotted at 5-day intervals. The 'active-break' monsoon sequence, which defines the major variations in rainfall within the established monsoon, is a common feature in the Australian monsoon region. Elucidation of the physical processes which control it is extremely important as forecasts on this time scale possess the maximum social and economic benefit. The study is being extended to the Australian summer monsoon but here the problem is more complicated because of the more complex geography of the Indonesian region.

These problems have been tackled in three ways by the Division, viz: a study of remotely sensed and conventional data, the development of theoretical and numerical models, and the use of laboratory models.

The data studies have centred on the Japanese Geostationary Meteorological Satellite which is positioned over West Irian. The rapid rate

of infra-red data acquisition (8 times per day) makes it possible to investigate diurnal cycles of the low latitude systems, whilst the permanence of the satellite permits the climatological structure of the region to be assessed. As an example, data from a satellite in the 1979 Global Weather Experiment have shown that the middle and upper level clouds which persist over regions of the tropics are — for considerable periods of time — extremely important in determining the equatorial radiation budget. It appears that the interaction of cloud decks with the radiation field provides heating rates which are comparable with the latent heat release associated with precipitation.

Second, theoretical and numerical models have allowed study of large scale features of the tropical atmosphere. These show sub-seasonal variations of the Asian summer monsoon and clustering of monsoon disturbances. It seems that the slowly varying sea-surface temperature and changes in the soil moisture, interact to modulate the more rapid changes in precipitation and evaporation.

Third, repeatable laboratory experiments using tanks of water have produced disturbances which behave in similar ways to full scale cyclones. (Details can be found elsewhere in this report under 'Geophysical Fluid Dynamics').

A joint tropical meteorology programme has recently been initiated with the Australian Numerical Meteorology Research Centre. The initial objective is to set up a sound data base for diagnostic studies which would provide a basis for the establishment of numerical weather prediction in the tropical Australasian and Indonesian regions.

## **VI. MISCELLANEOUS**

Prototype equipment has been installed on the east-west runway at Tullamarine Airport to determine the feasibility of measuring, remotely, and with sufficient accuracy, the water depth on the runway. A punched paper tape unit automatically records rainfall rate, wind speed and direction and water depth at four points across the runway. The results should also give an insight into the effect of wind drag on thin layers of water. This project is carried out in conjunction with the Australian Federation of Air Pilots and the Department of Transport.

Short range telemetry systems developed for airborne equipment have been successfully adapted for use in a variety of external research and industrial applications. A UHF radiosonde receiver and a pulse discriminator for use with photomultiplier systems, both of which were developed for use within the Division, are being examined by manufacturers with a view to commercial production.

As in the past, the Division remains an accredited laboratory of NATA (National Association of Testing Authorities) in the fields of 'Optics and Photometry' and in 'Flow Measuring Devices'. In both cases the numbers of radiometers and anemometers received for calibration have remained substantially unchanged.

During the last two years, radiation equipment together with assistance in its operation, has been made available to a number of organisations including the State Electricity Commission and the Victorian Department of Agriculture.

## **VII. PERSONNEL, AFFILIATIONS**

### **Awards**

Dr. G.W. Paltridge was awarded a Fellowship of the Australian Academy of Science.

Dr. W. Shepherd received the degree of Doctor of Applied Science from the University of Melbourne.

Dr. P.J. Webster was elected to honorary associateship of the Department of Mathematics, Monash University.

### **New Appointments**

Dr. W.L. Physick joined the Division from the University of Southampton to work on the general circulation of the atmosphere.

Dr. J.C. Scott was appointed from City University, London, to work on the lidar programme.

Dr. G.L. Stephens was appointed to work on climate aspects of clouds and radiation.

Dr. R.S. O'Brien joined the Division in 1979 to participate in the Stratospheric Balloon Program.

### **Secondment**

Dr. K.T. Spillane was seconded to the State Electricity Commission of Victoria for 9 months for special studies in connection with the Loy Yang Power Station.

### **Retirements**

Four long-serving members of the Division have retired — Mr F.K. Tighe, Divisional Administrative Officer (appointed 1947), Mr N.S. McLeod, carpenter (1953), Mr G.L. Garnham of the ozone group (1954) and Mr B.G. Collins of the radiation group (1958).

### **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 Australian Institute for Defence Science; the International Commission on Dynamic Meteorology; the ANMRC Policy Advisory Committee and the Latrobe Valley Airshed Study Steering 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; member of the Department of Science Baseline Atmospheric Pollution Working Group; Editorial Panel 'Boundary Layer Meteorology'; Academic Committee in Applied Sciences, Victoria Institute of Colleges.

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

Dr P.J. Fraser:— member of the Environmental Law Committee of the International Law Association; member of the Australian Department of Science and the Environment Working Group on the Baseline Air Pollution Station; member of the National Health and Medical Research Council Working Party on chlorofluorocarbons and alternative aerosol propellants.

Mr I.E. Galbally:— member of the International Advisory Committee for the SCOPE UNEP International Nitrogen Unit; member of the AAS National Committee on the Environment; member of the Australian Department of Science and the Environment Working Group on the Baseline Air Pollution Station.

Dr. J.R. Garratt:— member of WMO Working Group on Boundary Layer Problems.

Dr. R.N. Kulkarni:— member of the International Ozone Commission of IAMAP; Chairman of WMO Working Group on Ozone for Region V.

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

Dr. G.W. Paltridge:— Secretary of the International Radiation Commission of IAMAP; Chairman of the Working Group for JOC/GARP — Clouds and Radiation; member of Panel No. 3, International Commission on Atmospheric Electricity; invited expert to the JOC/GARP Board for Climate Studies; member of the International Climate Commission.

Dr. G.I. Pearman:— member of WMO CIMO Working Group on Environmental Pollution; member of WMO JOC/GARP Working Group on Data for Climate Research; member of Australian Department of Science and the Environment Working Group on the Baseline Air Pollution Station; member of the Commission on Atmospheric Chemistry and Global Pollution, IAMAP.

Dr. A.B. Pittock:— member of the High Altitude Pollution Program Scientific Advisory Committee, US Federal Aviation Administration; panel member of the Study on Sun, Weather and Climate, Geophysics Research Board, US National Academy of Sciences.

Dr. K.T. Spillane served on the Technical Advisory Committee to the Victorian State Plan to Combat Pollution of the Sea by Oil.

## **OTHER ACTIVITIES**

Sponsored by the Australian Academy of Science, National Committee for SCOPE and hosted by this Division, Mr I.E. Galbally organised a workshop on dynamic aspects of nitrogen cycling in Australian eco-systems. He and Dr. G.L. Stephens gave courses on lectures on composition and chemistry of the atmosphere, and on radiation transfer, respectively, to students in meteorology at the University of Melbourne.

Dr. A.D. McEwan was Visiting Research Fellow in the Research School of Earth Sciences, Australian National University, from March to June 1979.

Dr. P. Webster is coordinator of the Tropical Meteorology Program — a joint venture between the Division and the A.N.M.R.C. He is also Convenor, ICDM Symposium on Dynamics of Large Scale Low Latitude Circulation, to be held in Munich, 1981.

Dr. C.M.R. Platt was chairman in 1976-77 of an advisory board for the remote sensing course at Footscray Institute of Technology.

## VIII. OVERSEAS VISITS

Dr. G.B. Tucker made a number of overseas trips during the period, many of them a result of his membership of the JOC (Joint Organizing Committee) of GARP (Global Atmospheric Research Programme). These included:— during August/September 1977 a meeting of the JOC Board for FGGE (the First GARP Global Experiment) and a JOC officers meeting in Victoria B.C. Canada. During March 1978 he represented the JOC of GARP at the 7th Session of the WMO Commission for Atmospheric Sciences in Manila and later in June 1978 he attended a meeting of the JOC of GARP in Mexico. Three further visits, to Bracknell, U.K. in September 1978, to Dubrovnic, Yugoslavia in February/March 1979 and to Wellington, N.Z. in November/December 1979 were also to attend JOC officers meetings. These meetings were financed through WMO/ICSU GARP funds. Between April and July 1978 he spent six weeks at NCAR (National Centre for Atmospheric Research) Boulder, Colorado and at the British Meteorological Office, Bracknell, U.K. Early in 1980 he spent 2 weeks in Amsterdam at the JSC meeting of the World Climate Research Program.

During late 1977, the Assistant Chief, Dr. A.J. Dyer attended the IAMP/IAGA Joint Assembly at Seattle, and visited the observatories at U.S. Samoa, Hawaii and the headquarters at Boulder, Colorado, concerned with the global baseline station programme. He also visited participants from U.S.A., U.S.S.R. and Japan who had taken part in the 1976 ITCE hosted by the Division, to discuss points of detail arising from the analysis of the ITCE data.

For a period of 12 months during 1978-79, Dr. Pearman worked as a Research Associate of the Co-operative Institute for Research in Environmental Sciences, University of Colorado. During that time he was associated with the Geophysical Monitoring for Climatic Change Laboratory of the National Oceanic and Atmospheric Administration.

In March 1978 he was invited to act as Chairman of the Working Group on the carbon cycle at the Carbon Dioxide, Climate and Society conference held at the International Institute for Applied Systems Analysis, Laxenburg, Austria; and in July 1978 he spent one month as the guest of the Institute for Energy Analysis, Oak Ridge, Tennessee, preparing a report on the status of the global CO<sub>2</sub> measurement programmes.

As an invited participant Dr. Pearman took part in the following: WMO meeting on Research Aspects of Atmospheric Carbon Dioxide, Boulder, Colorado, October 1978; National Science Foundation meeting on Atmospheric Chemistry at the National Center for Atmospheric Research, Boulder, Colorado, October, 1978; WMO workshop on Global Carbon Cycle Modelling, La Jolla, California, March 1979; SCOPE Terrestrial Carbon Conference, Woods Hole, Massachusetts, May 1979. In August 1979 he attended the WMO Technical Conference on Regional and Global Observations of Atmospheric Pollution Relative to Climate, and a meeting of the WMO Working Group on Air Pollution, both held in Boulder, Colorado.

During June 1977, he organized a workshop on Atmospheric Carbon Dioxide and Climate which was sponsored by the Australian National Committee of the UN Study Committee on Problems of the Environment and hosted by this Division.

In August 1977 Dr. P. Fraser presented a paper at the IAMAP/IAGA Joint Assembly in Seattle: subsequently he visited (and gave seminars) at Washington State University and the NASA-Ames Research Centre, California. In August-September 1978 he conducted an interlaboratory halocarbon calibration experiment which involved measurements at several laboratories in the U.K. and in the U.S.A. He also attended and presented a paper at the 1978 American Chemical Society Annual Meeting as well as the 4th Meeting of the Atmospheric Lifetime Experiment (ALE), both in Miami, Florida. In August 1979 he presented several papers at the 4th International Conference of the Commission on Atmospheric Chemistry and Global Pollution and the WMO Technical Conference on Regional and Global Observation of Atmospheric Pollution Relative to Climate, both held in Boulder, Colorado. Following this he attended the 7th Meeting of ALE in Oregon and paid a short working visit to the Oregon Graduate Centre. In March 1980 he attended the 9th meeting of ALE and visited the NOAA-GMCC Observatory at Mauna Loa, Hawaii.

Dr. C.M.R. Platt spent ten months in the U.S.A. in 1976/77 mainly with the Cooperative Institute for Research in the Environmental Sciences, University of Colorado and with NASA, Langley, Hampton, Virginia. Whilst there he presented a paper at the August 1977 IAMAP Conference. In August 1978 he spent three weeks in the U.S.A. visiting (a) NOAA, Boulder for discussions on clear-air turbulence detection by radiometric techniques and (b) the New Mexico Technical Institute, Socorro, for talks on the STRATEX cirrus project. En route he attended a workshop on the Parameterization of Extended Cloudiness and Radiation at Oxford, U.K. Early in 1979 he spent a further two months at the New Mexico Technical Institute, Socorro, taking part in the CSIRO STRATEX experiment. During his trips to the U.S.A. Dr. Platt took the opportunity of visiting various institutions, universities, etc. connected with his work.

During the period Dr. P. Webster made a number of overseas trips in connection with the Winter/Summer MONEX (Monsoon Experiment), at the same time taking the opportunity of visiting MONEX centres in India and the U.S.A. In November/December 1977, as Consultant to the U.S. MONEX Committee he attended a Planning Meeting in Boulder, Colorado, visiting on the way the Japanese Meteorological Satellite Centre in Tokyo. Early in 1978 he was the Australian delegate to the 4th International MONEX Planning Committee in Kuala Lumpur: later, and in the same capacity he attended the 5th Meeting of the Planning Committee in Manila. In November/December 1978 he was principal scientist in the MONEX field phase at Kuala Lumpur and in July the following year, he took part in the field phase of the Bay of Bengal Experiment (Summer MONEX). In

England, in September/October 1978 he gave an invited paper on cloud and climate at the Oxford Radiation Conference.

Mr I.E. Galbally was an invited participant at the SCOPE/UNEP Workshop on Nitrogen Cycling in S.E. Asian Wet Monsoonal Ecosystems in Chiang Mai, Thailand, November 1979; and delegate of the Australian Academy of Science at the SCOPE General Assembly, Stockholm, in June 1979. He also spent a year, as a Nuffield Foundation Fellow, at the Division of Environment and Medical Sciences, AERE, Harwell, U.K., studying sulphur dioxide uptake by forest and grassland.

In February/March 1979 Dr. G.W. Paltridge took part in the STRATEX Experiment, New Mexico, and for the remainder of the time until January 1980 was Senior Visiting Fellow at the Cooperative Institute for Research in Environment Sciences, University of Colorado.

Dr. R.J. Francey spent three weeks in mid 1979, mainly at Lamont-Doherty Geological Observatory of Columbia University, New York, principally to take part in an international conference on 'Stable Isotopes in Tree Rings Research'.

Dr. R.N. Kulkarni visited Colorado in August 1977 for a comparison of ozone (Dobson) spectrophotometers. He also visited laboratories in Europe, Canada and the U.S.A. during September/October 1978 in connection with stratospheric ozone research. In January 1979 he spent time in Bangkok establishing an ozone station.

Dr. P.G. Baines visited New Zealand in 1977 for collaboration with the Meteorological Service. Recently he returned from a year at the Department of Earth and Planetary Sciences, Massachusetts Institute of Technology. Whilst in the U.S.A. he also spent time at the Joint Institute for the study of the Atmosphere and Ocean, University of Washington, and Woods Hole Oceanographic Institution.

In July 1977 Dr. A.B. Pittock visited Colorado to participate in a NASA (National Aeronautics and Space Administration) sponsored workshop on global ozone trends. Late in 1979 he completed a two-year appointment as a research associate at the Laboratory of Tree-Ring Research, University of Arizona.

Dr. R.A. Plumb attended the IAGA/IAMAP Assembly in Seattle, Washington, in August/September 1977. In October 1978 he again visited the USA to present papers to American Meteorological Society conferences on stratospheric dynamics.

In July 1979 Dr. G.L. Stephens commenced a 12 months attachment as a Postdoctoral Fellow at Colorado State University. His field is radiation/climate research.

In July 1979 Mr A.C. Dillely attended the International Lidar Conference in Munich, visiting en route a number of lidar centres in Europe, Canada and the U.S.A.

Dr. W. Shepherd spent November 1977 at meteorological organizations in India, Sri Lanka and Nepal with main interest in research in agricultural meteorology and its applications. He spent September/October 1978 in the Philippines and Republic of Korea as UN Consultant in Agricultural Meteorology and as adviser to the Institute of Geography, Academy of Science, Peking.

Mr I.C. McIlroy was the Australian delegate to two conferences on evapotranspiration conducted in Budapest, Hungary, in 1977 by WMO and the International Commission on Irrigation and Drainage.

Mr W. Knight has spent a year in the Department of Chemistry, York University, Toronto, concerned with instrumentation of stratospheric balloons.

Early in 1979 Mr G. Rutter spent some eight weeks in New Mexico establishing and supervising the computer facilities for the STRATEX experiment.

## IX. PUBLICATIONS

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