CSIRO

Division of Atmospheric Physics

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Commonwealth Scientific and Industrial Research Organization

AUSTRALIA

I INTRODUCTION

This is the last research report of the Division of Atmospheric Physics. The Division has now been amalgamated with the Division of Cloud Physics and the CSIRO component of the Australian Numerical Meteorology Research Centre to form the new Division of Atmospheric Research.

Over the 35 years of its existence the role of the Division remained, as it was at the outset, to conduct basic research into the physical processes underlying and controlling weather and climate. However progressive changes have occurred in the research programs tackled, reflecting perceived growing points in the advancement of meteorological science, developing scientific and technical skills, and newly emerging problems of relevance to the Australian community.

In general, the growing points have moved up the scale of phenomena, the earlier achievements in understanding micro-scale processes being used to study the larger meso-, synoptic-, and planetary-scale phenomena. Increased skills of note include laboratory experimentation of geophysical fluid dynamical phenomena, rapid developments in computers and numerical techniques, and the now ubiquitous satellite platforms and sophisticated remote sensing facilities. Perhaps the most notable emerging problem area concerns the increased awareness of the precious nature of the atmospheric environment. Accordingly, enhanced research on aspects of chemical constituents of the atmosphere on the local and global scale have been added to the classical physical and dynamical studies aimed at improving weather forecasting and understanding the physical basis of climate.

A common feature of the (old) Division of Atmospheric Physics and the (new) Division of Atmospheric Research will be the range of techniques used to break new ground. A broad attack is essential because the scales of atmospheric phenomena of interest virtually prohibit true experimentation. Therefore the use of theory, laboratory models and numerical studies must be strongly backed by field programs and diagnostic investigations of global data to ensure that deductions using surrogates are relevant to the real system.

G.B. TUCKER
Chief of Division.

II DYNAMICS RESEARCH

The objectives of the dynamics research program are, in broad terms:

(i) The increase of our understanding of the dynamics and physics of the atmosphere and, to a lesser extent, of the oceans.

(ii) The use of this increased understanding to develop procedures and models to improve short and long-term weather forecasting and prediction of other socially and economically significant environmental variables, such as the concentration of atmospheric pollutants and the large-scale atmospheric transport of chemical constituents.

These objectives have been pursued on a broad front, employing field observations, theoretical modelling and laboratory experiments. Activities range from the largest atmospheric scales through mesoscales to the small-scale dynamics of the atmospheric surface layer, and to the dynamics of the near-shore regions of the ocean, especially when it seems likely that the latter will increase understanding of atmospheric phenomena.

For present purposes, descriptions are divided, rather arbitrarily, into three areas - large-scale dynamics which embodies geostrophic flow,* small-scale dynamics which involves sub-geostrophic flow, and geophysical fluid dynamics involving primarily laboratory-tank experiments.

* Geostrophic = balance between horizontal pressure gradient and effect of earth's rotation.

A LARGE-SCALE DYNAMICS

The Quasi-biennial Oscillation

The quasi-biennial oscillation is a remarkable quasi-periodic phenomenon which manifests itself most clearly as an alternating sequence of easterly and westerly winds in the tropical stratosphere. The oscillation is the dominant feature of the dynamics of this region.

Over the past four years the phenomenon has been studied using theoretical, laboratory and numerical techniques. First the existing theory was modified to correct some conceptual errors; this led to a successful laboratory analogue of the oscillation which has proved a major factor in gaining widespread acceptance of the theory, and finally the phenomenon has been successfully reproduced in a numerical model of the low-latitude, stratospheric circulation. This was the first simulation of the three-dimensional structure of the oscillation and diagnosis of the model's evolution has highlighted some important and hitherto unrecognized features of the underlying dynamical mechanisms.

Stratospheric Warmings

Under normal conditions the winter stratospheric polar region is very cold during the polar night. Occasionally, however, the temperature in this region may rise, in a few days, by as much as 50°C (less in the Southern Hemisphere). This "stratospheric warming" phenomenon is, on the basis of observational evidence, clearly associated with large-scale planetary wave motions which amplify strongly at such times. Previous theoretical work has explained how such warmings are produced by the poleward heat transport in amplifying planetary waves, but without explaining the reasons for the amplification. This question has been addressed in the Division along two lines. Techniques developed to evaluate the stability of atmospheric flow patterns have been applied to winter stratospheric conditions, and the dynamics of the interaction between planetary waves and the background flow has been studied in a simple model of nonlinear planetary waves. Together, these studies suggest that under certain circumstances the winter stratospheric flow may be unstable and that the stratospheric warming phenomenon is a manifestation of the consequent breakdown of the flow.

Theory of the Role of Transient Eddies in the General Circulation

While it has long been recognized that synoptic-scale, transient eddies (weather systems) play a significant role in the atmospheric general circulation, our understanding of their impact is far from complete. Over the past decade, developments in the theory of the interaction between eddies and the zonal mean (longitudinally-averaged) flow have led to major advances in our understanding of the circulation of the stratosphere, where the background flow is longitudinally uniform. In the troposphere, however, departures from longitudinal symmetry are large and climatologically important and therefore these techniques have proved to be of limited usefulness in this region. Now similar techniques have been developed in the Division which do not require longitudinal symmetry of the background flow; these techniques are being applied to climatological data with the aim of clarifying the effect of the transient eddies on the climatology of the tropospheric circulation.

Atmospheric Blocking

The weather in the mid-latitudes of both the Northern and Southern Hemispheres often includes eastward progression of storms, associated with low-pressure systems and fronts, which are interspersed with periods of fair weather, associated with high-pressure systems. The west-east (zonal) component of the accompanying wind is usually strong while the south-north (meridional) component is usually weak.

Occasionally, the eastward progression of storms and anticyclones is blocked by a combination of a high and a low-pressure system. The block has its principal warm high-pressure system displaced polewards of the cold low-pressure system thus creating a pressure dipole. There may also be a series of dipole replicas of alternating sign extending downstream of the main dipole. A stable flow configuration is set up, which is characterised by enhanced meridional and reduced zonal flow in mid-latitudes.

These blocks occur only in certain geographical locations, for example the northeast Atlantic and northeast Pacific oceans and the Tasman sea. They occur more readily in certain seasons, particularly winter. Blocking pairs may have a profound effect upon the weather and climate in both hemispheres. For example, during the southern winter of 1982, persistent and recurring blocking dipole pairs occurred in the Tasman sea. This led to abnormally cold temperatures and severely reduced rainfall in south-eastern Australia.

Until recently there was no universally accepted theory of the formation, maintenance and decay of blocks. However, in the last two years work in the Division has elucidated how the high-low dipole blocks occur and why they are nearly stationary. The three-dimensional instability theory is able to provide a unified approach for explaining both of the principal weather regimes - the single low- and high-pressure systems that propagate rapidly eastwards and the stationary dipole blocks. The theory successfully predicts areas of cyclogenesis for given hemispheric flows and explains the average monthly storm tracks and associated eddy fluxes. It also captures the preferred geographic locations of both developing and mature blocks. In particular, the type of disturbance responsible for triggering the atmosphere into the blocked flow regime was first predicted by the theory.

Atmospheric Response to Sea Surface Temperature

A simple model has been used to study the mechanisms which control the local and remote (teleconnection) responses of the atmosphere to the thermal forcing resulting from sea surface temperature (SST) anomalies. Depending on the latitudinal location, two major limits of atmospheric response may be identified. The first, the "diabatic limit", occurs with the SST anomaly embedded in weak low-latitude basic flow and results in a strong enhancement of the initial anomaly response through a vigorous positive dynamics-diabatic heating feedback. Strong teleconnections are evident between low and high latitudes. The second domain, the "advective limit", occurs when the SST anomaly is placed at higher latitudes in the vicinity of the westerly maximum. The local response is extremely small due to the creation of an indirect zonal circulation in the vicinity of the anomaly.

The model results were used to interpret experimental results obtained from general circulation models and provided a rationale for the existence of teleconnections found between low and high latitudes when SST anomalies were imposed in the equatorial oceans.

In a separate investigation, seasonality of responses was investigated. The extratropical regions of the winter hemisphere appeared to possess strong teleconnections with equatorial forcing but weak or non-existent connections with local heating anomalies. In an apparent contradiction the extratropical regions of the summer hemisphere were quite sensitive to local thermal forcing but apparently unaffected by the remote forcing from equatorial regions. The sensitivity of the middle latitudes to remote (equatorial) forcing is shown to be a function of the relative location of the SST anomaly with respect to the zeros of the basic flow and the magnitude of the mid-latitude westerlies.

B SMALL-SCALE DYNAMICS

Turbulent Dispersion Studies

The dispersion of pollutants in the atmosphere (and in rivers, lakes and oceans) is achieved by turbulent flow. This process is much more effective than molecular diffusion but is also more complicated, because the turbulent eddies involved are generally comparable in size with the plume or cloud of pollutant being dispersed.

Fluid flow and contaminant transport can be described in two ways. The Eulerian description is in terms of the velocity and contaminant concentration at fixed points within the fluid. The alternative Lagrangian description considers the velocity of small elements of fluid ("marked particles") as they move about. So long as the effect of molecular diffusion is negligible, as in geophysical flows, these marked particles retain their initial concentration. The Lagrangian description is more appropriate when considering contaminant material - any approximations involve only the velocity statistics of the marked particles and are thus independent of the contaminant distribution. In contrast, approximations made in the Eulerian framework necessarily involve both the velocity of the fluid and the concentration of contaminant.

A picture of the average concentration of contaminant can be built up by following the distribution of a suitably large number of marked particles and the variability of the concentration may be calculated from the distribution of a large number of pairs of particles. Models for both concentration and variability embody features such as the intensity, size and lifetime of turbulent eddies. Studies are concerned with increasingly complex situations - stationary, homogeneous turbulence with a uniform or a spatially-varying mean wind, neutral turbulence where the boundary, for example, the earth's surface, results in a vertical shear in the mean wind, non-neutral boundary-layer turbulence, and a convectively mixed layer where buoyant motions dominate the turbulence but are strongly modified by the lower and upper boundaries, as between the earth's surface and a temperature inversion.

Two distinct gas tracers were released from separate points during field experiments and sampled continuously at a third point. These experiments enabled various concentration statistics to be determined. They provided, in particular, boundary-layer data on variations of concentration of pollution from an isolated source and on the way in which multiple sources interact and tend to smooth out variations. Analogous experiments were conducted in a simulated boundary layer in the wind tunnel of the Division of Environmental Mechanics.

Slope Winds

Night-time cooling of near-surface air layers may generate katabatic (down-slope) winds. This can occur on quite gentle slopes and result in a body of cooled air collecting at the lowest point. The result is a stable stratification in the lower atmosphere which tends to trap any airborne pollutants.

Earlier work in the Latrobe Valley, an electricity-generating area to the south-east of Melbourne, involved tethered-balloon sondes winched up and down repeatedly between the surface and 200 m height. It confirmed that the most important force retarding down-slope flow is 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. The other retarding force - friction at the surface - is effectively decoupled from the flow by strong near-surface stability. Conditions for onset of down-slope flows as functions of cooling rate, ambient wind strength and stability of the air have been studied.

Current work centres on up-slope winds resulting from solar heating of the slopes. Laboratory experiments and theoretical modelling indicate an important role for these flows in the ventilation of valleys in light wind conditions.

The Blocking Effect of a Ridge on the Wind

Data collected previously during studies of down-slope cold-air drainage (katabatic) winds have been analyzed to show the blocking effect of a ridge on a stably-stratified flow (in which the air is colder and denser near the ground than aloft). Such blocking occurs when the wind has insufficient energy (i.e. the speed is too low) to lift the denser air over the ridge. This simple physical picture enables the formulation of a criterion for the depth to which the flow is blocked in terms of the wind speed, the height of the ridge and the density gradient of the air. The observations and the blocking criterion are consistent with earlier numerical and laboratory modelling.

Valley Circulations in a Crosswind

Previous numerical and laboratory experiments showed that stagnant air trapped in a valley can be swept out by a cross-wind if a Froude number (based on the air stability and depth of the valley) exceeds a critical value. Field experiments have confirmed this work but suggest a higher value (1.6 cf. 1.3) for the critical Froude number.

A simple model of the diurnal planetary boundary layer has been developed. Drawing on contributions to the oceanographic literature, the model is the first of its kind to incorporate the effects of wind-shear generated entrainment and is free of adjustable parameters. Detailed comparison with published field data shows that the model has good prediction capability for mixed-layer depth, temperature and wind velocity - the major parameters required for lower-atmosphere pollution dispersion studies.

The model emphasises the role of mean-flow instabilities (i.e. instabilities on length scales of the depth of the mixed layer or larger, as distinct from length scales associated with billow turbulence) in the growth of the mixed layer. These instabilities occur when the kinetic energy of mean motion of the layer exceeds a measure of the stability of the layer relative to ambient conditions.

This "Froude dynamics" approach indicates that strong growth of the duirnal mixed layer occurs when wind shear between mixed layer and ambient air is large and not so much when surface heating is large.

Latrobe Valley Sea Breezes

Analysis of surface wind data for the Latrobe Valley has revealed the existence of sea breezes which regularly penetrate to Morwell, 85 km up the Valley from the east coast (Figure 1). In mid-summer the sea-breeze frequently advances to Yarragon, 110 km inland. A less regular sea breeze from the south coast is sometimes detected at Hazelwood, arriving from the southwest via the Boolarra gap.

This sea-breeze climatology has been combined with aspects of studies elsewhere examining the role of the sea breeze in the dispersion of pollutants. With the current distribution of emitters in the Valley, it appears the arrival of the sea breeze may improve the air quality in all regions, although on occasions it may transport emissions to the upper part of the Valley beyond Yallourn. A field study has been proposed to further examine these ideas.

Internal Gravity Waves - Turbulence

Internal gravity waves are important for many smaller-scale processes in the ocean and atmosphere, but their study has lacked an adequate dynamical framework taking into account both the statistical and non-linear nature of the problem. An available statistical theory is only valid for infinitely weak nonlinearities, and therefore does not apply to oceanic or atmospheric internal waves.

A new statistical dynamical theory, valid for both strong and weak nonlinearities, has recently been developed at the Division by applying the novel approach of reformulating the problem as an equivalent quantum field theory.

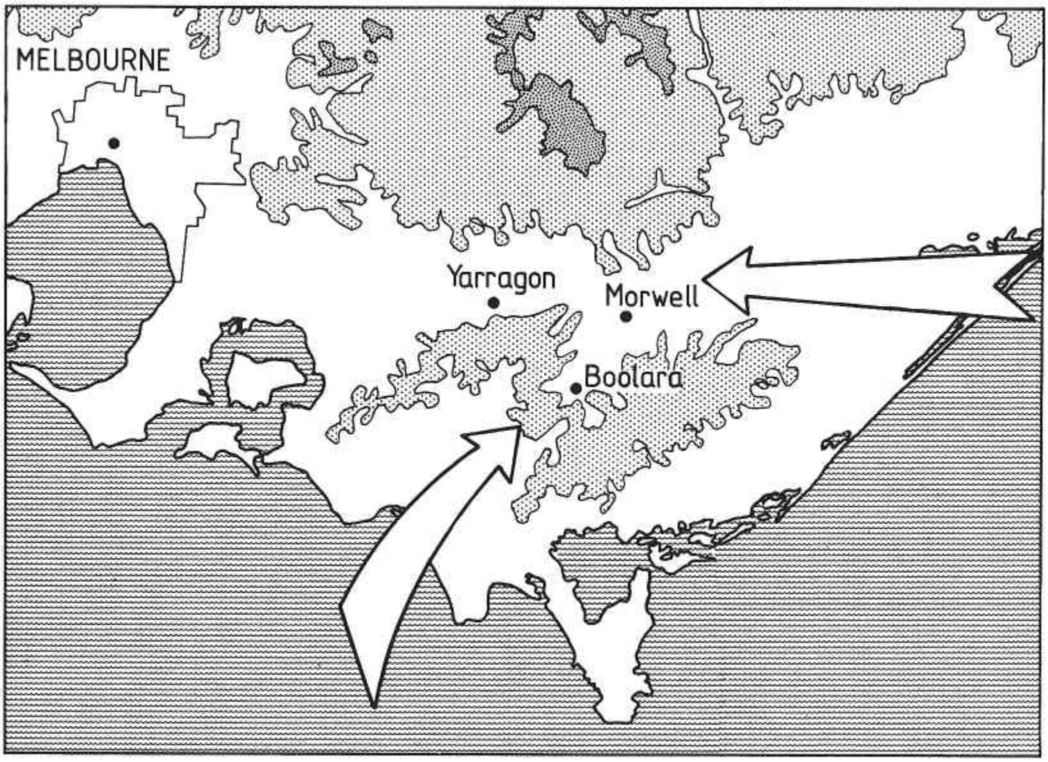

Fig.1. Latrobe Valley region of south-east Australia. Direction of sea-breezes is indicated (see text).

Atmospheric Boundary Layer

Turbulent transfers. A comprehensive investigation of flux-profile relationships in the lower atmosphere for the unstably stratified (daytime) case, based on the Division's earlier data from Kerang and Hay sites, has been completed. This gives a tight determination of the thermal stability relationships. It determines the effective von Karman constant in the flux-profile relationship for heat or water vapour transfer as 0.416, within a remarkably small experimental standard error of 0.6 per cent. (This effective value in flux relationships is completely independent of a current controversy about the value of von Karman's constant in the wind profile.) It also identifies a departure from the conventional similarity scaling in winds lighter than about 4 m/s, evidently due to the intermittent onset of free convection.

These results, apart from providing a basis of comparison for theoretical models of turbulent transfer, can be used in practical applications either directly or in the building up of improved bulk transfer relationships particularly for use over the sea.

Evaporation. A new type of combination method developed in the Division for determining evaporation and surface (stomatal) resistance is based on the measurement of bulk quantities (wind speed plus air temperature and humidity at some suitable height) together with the Bowen ratio (from measured differences of temperature and humidity between two heights) - the bulk-Bowen or (BB) method. On the other hand, the well known Penman-Monteith (PM) method is based on measurement, or climatological specificiation, of the bulk quantities together with heat-energy input from radiation.

Either combination method can be used in two modes. One is to determine the surface characteristics - resistance and bulk transfer coefficient - for a particular vegetated surface, from suitable measurements which must include independent measurement of the evaporation; here the BB method should be used. The other mode is to evaluate the evaporation without the difficulties of measuring it directly, by making only the measurements for a combination relationship when the two surface characteristics are already approximately known; for this the PM method should be used.

A trial application of the procedure to the Division's data from a grassland site at Kerang, using the BB method to determine overall surface characteristics and then the PM method to evaluate the evaporation for each 30-minute run, has lent strong support to the validity of the approach. The experimental scatter in the evaporation for the individual runs from the combination method, relative to that independently measured, is represented by a standard deviation of only 5 percent.

Modelling the boundary layer. A simple, but realistic, 3-layer model of the daytime unstable atmospheric boundary layer has been used to predict wind components and velocity defects (real wind minus geostrophic wind) in terms of entrainment, thermal wind and accelerations. The predicted quantities were compared with observations from 3 field experiments (AMTEX, WANGARA, KOORIN - see previous reports) and generally showed good agreement. Basically the wind components were not significantly affected by the above effects, implying an internal equilibrium with the turbulence field. In contrast the velocity defects showed a strong dependence on these factors, and imply that the main response of the boundary-layer flow to entrainment and advection is a rotation of the layer flow towards the externally-imposed pressure-gradient flow. Use of a second-order turbulence-closure model of the nighttime boundary layer allowed two major studies to be performed - first, investigation of the radiative cooling effects within and above the nocturnal boundary layer by coupling the turbulence model to a long-wave radiation model, and, second, simulation of observed properties and interpretation of low-latitude behaviour (analysis of KOORIN observations).

The first study showed that thermodynamically the nighttime layer develops a three-layer structure. In the lowest tenth and uppermost fifth of the layer radiational cooling dominates the total cooling, while in the central region, occupying most of the layer, turbulent cooling dominates. At the top, radiational cooling is a significant fraction of the surface cooling rate. Radiation effects are greatest above the layer, where large gradient Richardson numbers are generated. Consequently turbulence in this region decays rapidly after sunset, aiding the development of the nocturnal jet. In the absence of such effects a much slower decay occurs.

In the second study, involving observations of the nocturnal boundary layer and model simulation, mid-latitude observations (mainly in terms of evolution of the depth and its dependence on surface turbulent fluxes) were generally consistent with model calculations for horizontally-homogeneous terrain. Low-latitude observations of non-dimensional depth were significantly smaller than those at mid-latitude, apparently the result of katabatic flows at the site and not the difference in latitude. This is consistent with model calculations for non-zero slope terrain.

Cold Fronts Research Programme (CFRP)

The CFRP, a long-term study of cold fronts and associated phenomena in south-east Australia, has now completed two of its three planned observation phases and, in all, nine 'frontal' events were identified, with most being observed simultaneously by research aircraft, radar, upper-air soundings and a surface network of instruments. Several of the events are of particular interest because of their detailed mesoscale structure related to the presence of thunderstorm bands. To date analysis of these observations has considerably extended our knowledge of the frontal 'transition' zone (FTZ), with its 'changelines', rainbands and associated cloud bands. Figure 2 shows mesoscale cloud bands B, C and D making up a frontal transition zone. Band D later grew into a vigorous squall line producing a major pressure-jump line and a mesohigh pressure feature at the surface.

Important features of the frontal zone include -

(a) The multiple-line nature of the transition zone.

(b) The main component of the FTZ comprises one or two active squall lines, with associated pressure-jump line, the latter being the result of a cold-air outflow from the squall line in its direction of movement.

(c) The frontal region is characterised by an evolving mesoscale surface pressure field which has a considerable dynamical influence on low-level winds. Observations from several fronts have been simulated using a simple 'slab' boundary-layer model and an appropriate time sequence of mesoscale horizontal pressure gradients corresponding to the passage of a mesohigh. Figure 3 shows the surface pressure field corresponding to the FTZ illustrated in Figure 2. Contours are isobars in tenths of mb above 990 mb. Pressure features are identified by H1-H2, L1-L4. Change line $D_{2,3}$ corresponds with leading edge of cloud band C (appropriately displaced to the east) and line D_f with rear edge of cloud band D. Mesohigh H2, coinciding with the rainband, is produced by evaporation of rain at low levels and the subsequent cold outflow gives the pressure-jump line D_4. Most features were moving from west to east at about 15 m/s.

(d) Dynamically the region of the FTZ comprises a pre-frontal and a weak post-frontal jet, both being determined by the thermal-wind field. Within the FTZ the wind field and circulation pattern are dominated by the main squall line, with maximum upwards vertical velocity of 0.2 m/s ahead of the squall line and maximum downwards of 0.1 m/s behind, on a horizontal scale of 100 to 200 km. Maximum cyclonic vorticity at a height of about 1 km is found in the region of the squall line.

(e) Frontogenetically the FTZ is active in the Mt. Gambier region, with contributions to frontogenesis (i.e. increase in temperature contrast across the front) from both low-level divergence and deformation.

Future work in the field includes the final phase of the CFRP to study evolution of the transition zone between Mt. Gambier and Melbourne.

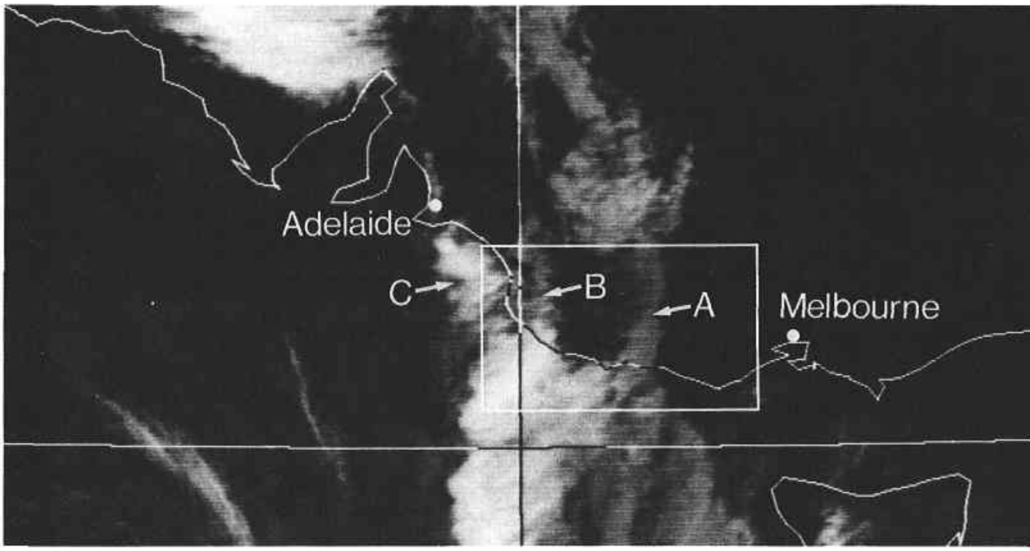

Fig.2. Satellite photo at 0000 GMT (1100 Eastern Summer Time) on 23 November 1981 showing mesoscale cloud bands (A,B,C) making up a frontal transition zone over Mt. Gambier, S.A. (see text).

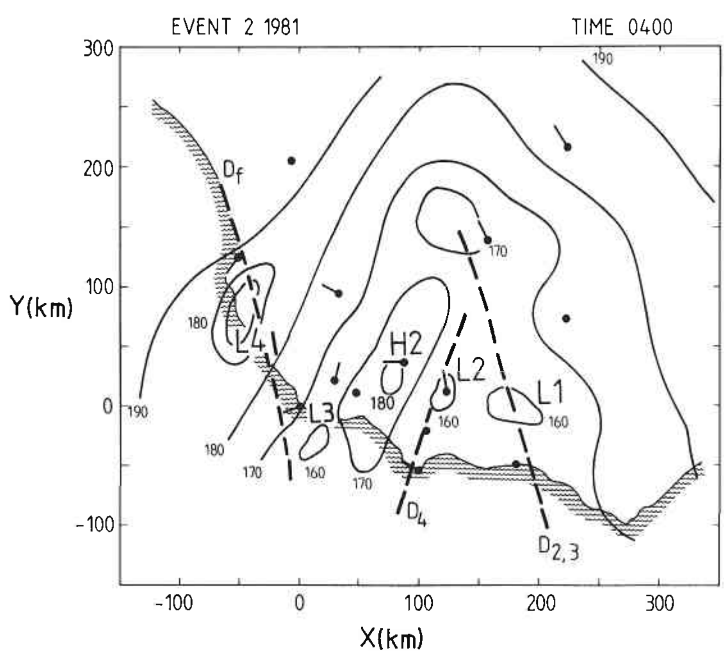

Fig.3. Surface pressure field at about 0400 GMT corresponding to the frontal transition zone in Figure 2. Origin (x,y) at Pelican Point, S.A.

International Turbulence Comparison Experiment (ITCE)

The previous report of the Division described some findings of an extensive field experiment carried out in 1976 at Conargo, New South Wales - the International Turbulence Comparison Experiment. The experiment compared the performance of turbulence sensors a few metres above the surface, and investigated flux-profile relations, particularly calculation of the von Karman constant of the wind profile in the atmospheric surface layer - a vital component of turbulence research.

Recent work on the data gave a value for the constant close to 0.4, established this value as suitable for the atmosphere and gave a basis for judging the reliability of earlier world-wide experiments. Results emphasised the important effects of statistical error, flow distortion and sensor separation upon turbulent flux measurements.

C GEOPHYSICAL FLUID DYNAMICS

Non-Linear Effects in Stratified Flow over Topography

Effects of topography on atmospheric motions are not fully understood and this places significant limitations on, for example, large-scale atmospheric models. However, in recent years advances have been made. The procedure has been to study certain simple systems as a guide to the behaviour of more varied systems, and the atmosphere in particular. Work has concentrated on non-rotating two-dimensional flows.

A laboratory study of two-layer liquid flow over obstacles has been carried out to investigate and describe the non-linear flow properties upstream and downstream. A successful theoretical description of the observed phenomena has been obtained, and indicates how the procedure may be generalized to more realistic atmospheric flows. Several non-linear features of the flow which have atmospheric analogues, such as internal undular bores and (probably) hydraulic drops have been described in detail for the first time.

Internal Tide Generation

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.

Internal tidal motions in the ocean are important because they may constitute a dominant portion of the water motion near the edges of continental shelves where they are generated, and hence are significant for oil drilling and pipelines, pollution dispersal and biological processes. The generation process occurs because the density-stratified water is advected over bottom topography by the surface tide. Theoretical models for internal tide generation have been extended to the point where they may be readily applied to continental shelf/slope geometries with realistic oceanic density stratifications, provided that the topography is reasonably two-dimensional. The models have been applied to all of the world's continental shelves, and the regions with the largest internal tide generation have been identified; the Australian north-west shelf is one such region (Figure 4).

Three-dimensional topographic features complicate the internal tide generation. The most common such features on continental shelves or slopes are submarine canyons, and inside these the tidal motions (as well as some other motions) are anomalously large. A laboratory experiment has been carried out to investigate this, and it is now known that the reason for

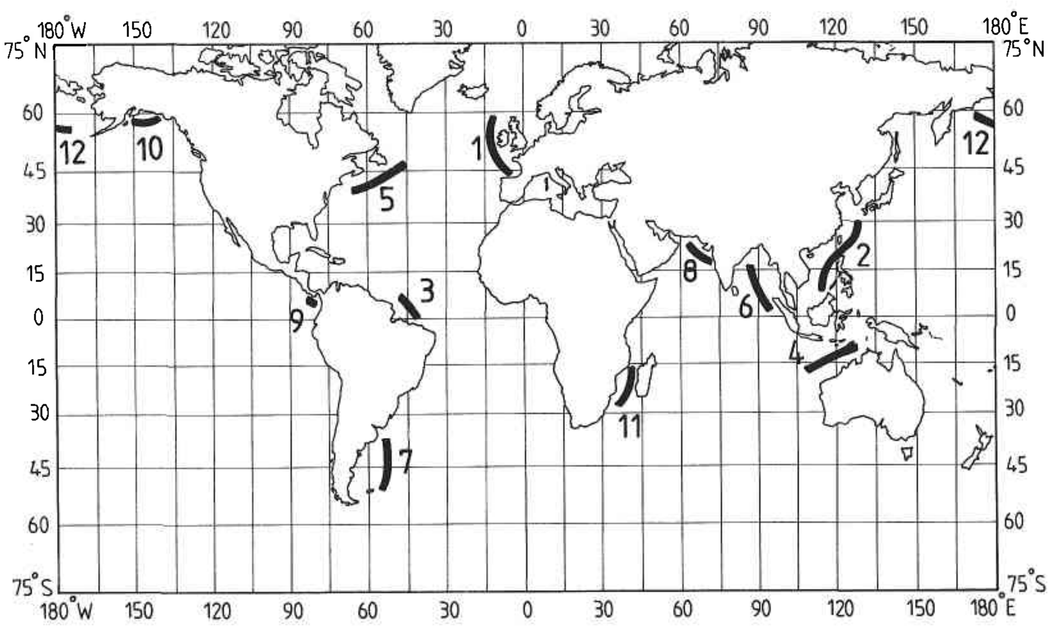

Fig.4. Coastal regions of the world with substantial internal tide generation, numbered in decreasing order of magnitude as calculated from a theoretical model.

this phenomenon is, in part, that internal waves inside submarine canyons behave like sound waves inside organ pipes, in that the waves reflect from the open end. A generation theory appropriate for submarine canyons has been developed.

Bass Strait Density Stratification

The nature of the density field in Bass Strait, between the Australian mainland and Tasmania, is of vital importance for physical processes in the region such as mixing processes, turbulent diffusion and current structure, and processes dependent on internal wave propagation. A study of the monthly variation of this density field has revealed that Bass Strait water is strongly stratified in summer but is well mixed in winter, and that this variability is controlled by the competing processes of surface heating and tidal bottom stirring, with wind stirring a secondary factor except in winter.

III ATMOSPHERIC RADIATION RESEARCH

This program is concerned with the flows of solar and terrestrial (heat) radiation through the atmosphere and at the earth's surface. These flows produce the regions of heating or cooling which drive the global atmospheric circulation, with winds blowing from areas of cooling to areas of heating, both at surfaces and in the atmosphere. Investigations can be divided conveniently into strategic long-term studies of the interaction of radiation with the atmosphere, and applied studies concerned with the involvement of radiation in problems of the environment.

The strategic studies aim to increase understanding of how the atmospheric system is forced by the absorption of radiation. Such knowledge is vital to progress in the understanding and prediction of climate, on the long timescale, and to forecasting of the weather, on the shorter timescales. Until recently there has been little understanding of the interaction of solar and terrestrial radiation and clouds. This is partly because clouds are so diverse but more importantly because, first, they scatter as well as absorb radiation and, second, they consist of water droplets in the lower atmosphere and ice crystals in the upper atmosphere. The scattering properties of water droplets can be predicted but the many different types of ice crystals complicate the scattering properties of clouds considerably.

The interaction of clouds and radiation has been recognised by the World Climate Research Program of the World Meteorological Organization (WMO) as a major component of climate. Meteorology is by its nature a global study, and the Division is committed to participation in international radiation programmes. This focus will, in the long term, be of immense benefit to regional areas, such as Australia, whose climate is affected by distant events in, for example, the Pacific area.

The Division has built up a formidable range of techniques, both experimental and theoretical, for study of radiation. A recent acquisition is a satellite reception centre which will enable direct reception and sophisticated processing of cloud data embracing a vast region around Australia. It is known as "CSIDA" - an acronym from CSIRO System for Interactive Data Analysis. For many years the Division of Cloud Physics has cooperated with the loan of an instrumented aircraft for cloud-related studies. With the amalgamation of the Division of Cloud Physics and the Division of Atmospheric Physics, the facilities will become fully integrated.

Applied studies in the group have involved mainly remote-sensing techniques, for example for identifying cloud amount and type from satellite data and determining sea surface temperature around the Australian coast. A major new initiative has been the development of a pulsed infrared laser radar (lidar) for several applications, such as the detection of cloud height and formation of fog at airports and the measurement of profiles of pollutant gases in the atmospheric boundary layer. The lidar will also be used in cloud-radiation studies.

The Division maintains several standard solar radiation measuring instruments. These are available to industry for calibration purposes.

A RADIATION INTERACTION WITH CLOUDS

Transfer Through Three-dimensional Clouds

The general practice in considering radiation transfer through clouds was until recently to treat clouds for theoretical purposes as horizontal layers of large extent and homogeneous in quality. This enabled a simplified two-dimensional treatment. Real clouds, however, never attain these qualities, although it is found that extended stratus or altostratus clouds can often be treated as infinite layers. Cumulus clouds are a good example of three-dimensional "finite" clouds which must be treated in a three-dimensional manner.

A fundamental theoretical method for treating three-dimensional transfer in a scattering medium has been developed at the Division. This method transforms the three-dimensional equations into a two-dimensional format involving varying scatter. The development of this method allows the prediction of radiation transfer through cumulus clouds and other three-dimensional media.

Radiation and Microphysics in Ice Clouds

One aim of cloud-radiation research is to develop a simple but sufficiently accurate model for the transfer of radiation through clouds. For instance, it is convenient to specify reflection of solar radiation from clouds or the emission of infrared radiation in terms of quantities such as temperature or liquid water content and bypass the details of cloud particle size. This was achieved previously for water clouds, and the emphasis has now shifted to ice clouds. Two approaches have been considered. First, the relations of reflection and emission to basic cloud particle shapes and sizes have been studied. The information has been applied to producing a parameterization. Second, the emission and reflection properties have been studied remotely using lidar and radiometer methods from the ground. It has been found, for instance, that emission and reflection often vary with cloud temperature, and this information is of immediate empirical use in atmospheric models. Furthermore, backscatter properties of the clouds vary systematically with temperature and this variation is apparently related to crystal type. The lidar data have led indirectly to the possibility of parameterizing the optical properties of ice clouds in terms of temperature and liquid water content.

A further study of ice clouds in the tropics at Darwin in 1981 using the Aspendale lidar and radiometer revealed many interesting properties of clouds associated with thunderstorms, as well as clouds associated with synoptic situations. The backscatter properties are being compared with the properties of mid-latitude cirrus clouds.

The Influence of Radiation on Ice Cloud Particle Growth

Cloud particles (water droplets or ice crystals) grow when the air is saturated and water vapour condenses out onto the particles. These particles are heated or cooled by radiation, causing a difference in temperature between the particle and it environment. A study of this effect in high ice clouds, where particles are generally falling under gravity, indicate that the radiation component can have a significant effect on cloud particle growth.

Cloud-Radiation Interaction and Climate

The basic knowledge of radiation transfer through clouds gained over the past few years has been applied to simple energy-balance models of the climate. The optical properties of a number of cloud types were introduced in a systematic manner. The models were found to be highly sensitive to cloud height for all cloud types, and also to the liquid water path through the cloud. They showed that high, thin clouds have a warming effect, whereas low clouds have a cooling effect. They demonstrated once again the importance of the accurate specification of cloud optical properties in cloud models.

B SATELLITE STUDIES

Detection of Cloud Type and Amount from Satellites

Meteorological satellites now provide a comprehensive view from space of the earth and its atmosphere. It is usually quite obvious, through solar reflection or infrared emission, which areas are covered by cloud. It is not so obvious how broken cloud or cloud type, density and height can be determined. Recent research in the Division has involved both basic theoretical work on converting radiances at the satellite into cloud information and work, using existing methods with the necessary development, to map clouds on a seasonal and global basis.

An example of the latter is the analysis of two and a half years of data from the selective-chopper radiometer on the NIMBUS 5 satellite to produce a global climatology of high-level ice clouds. The technique was based on the differential absorption of reflected solar radiation at two separate wavelengths in the carbon-dioxide and water-vapour absorption bands near 2.7 μm. The analysis showed the high level clouds associated with the monsoons and the tropical convergence zone as well as the absence of high clouds over arid areas and eastern portions of the major oceans. It also showed year-to-year variations of the extent of high clouds.

The International Satellite Cloud Climatology Programme, in which the Division is involved, has been set up by WMO to map the global cloud amount and type on a systematic basis for several years. A recent study has concentrated on inferring cloud properties from radiometers on board geostationary satellites. For instance, satellite data for the Australian region can be obtained every three hours from the Japanese Geostationary Satellite. Using basic radiation properties of clouds which have been discovered over the past decade, a method has been developed to distinguish cloud type, height and amount.

With the acquisition of the CSIDA satellite reception facility (see above), the methodology for obtaining cloud information will be greatly strengthened.

Satellite Measurement of Sea Surface Temperature

Techniques involving the use of more than one satellite radiometer channel to obtain an accurate measurement of sea surface temperature (SST) are under investigation. Theoretical models are used to predict the attenuation of infrared radiation as it traverses the atmosphere to the satellite. The major absorber is water vapour with smaller contributions from minor atmospheric constituents including methane, carbon dioxide and aerosols. Algorithms have thus been derived for evaluation of the window channels on the NOAA series of orbiting satellites.

Ground-truth data have been collected to test these algorithms. High-resolution satellite data have been supplied by the New Zealand Meteorological Service and these have been supplemented by radiosonde and ground-based radiometer measurements as well as boat measurements of SST. The algorithms were found to perform well in our temperate latitudes and future work will test their applicability in more tropical areas. In the future, efforts will also be directed at gaining more accurate measurements in partly cloudy conditions. This project will be one of the main programs of the new CSIDA facility.

C ENVIRONMENTAL STUDIES

Ultraviolet Radiation Monitoring Network

The Australian network of instruments measuring sunburning ultra-violet (UV) radiation has been closed down. However long-term variations in shortwave UV flux continue to be monitored at Aspendale and Brisbane by instruments similar to those operated by Temple University, Pennsylvania. The Australian measurements have been calibrated and archived and will be used in a detailed comparison with measurements of visible solar radiation.

Atmospheric Turbidity at the Baseline Station

One of the long-term studies at Aspendale has been the annual variation of the atmospheric turbidity, a quantity which measures the effect of dust in the atmosphere on solar radiation. Increasing human activity can lead to a build-up in the dust, or haze, content of the atmosphere, leading to a decrease in solar radiation at the surface and to subtle climatic effects.

Turbidity measurements have now been transferred to the Baseline Station at Cape Grim, north-west Tasmania (described in a later section). Turbidity is monitored at two wavelengths. It is extremely low but when the wind blows from the north, the 'plume' from Australia, and particularly Melbourne, can be seen very clearly. An unexplained annual variation in the 'clean' air has also been detected, with a marked minimum in winter.

Environmental Applications of the Infrared Lidar

The lidar or laser radar (described earlier) can be tuned over many wavelengths between 9 μm and 11 μm. Absorption bands of several gases which exist in the atmosphere, e.g. water vapour, ozone and methane, are within this range. Concentrations of these atmospheric constituents, and others, can thus be monitored.

The lidar also has applications at airports, where it could monitor cloud base and the formation of fog and it has important potential for forecasting applications. Thus the wind speeds determined by satellite measurement of cloud movement can be converted to wind heights by corresponding lidar cloud height measurements. This is particularly important for high clouds whose altitudes cannot easily be determined.

D RADIATION STANDARDS

Recording of the main solar radiation parameters at Aspendale ceased in 1980. Recording of radiation parameters is now concentrated at the Baseline Station at Cape Grim. The Station is a more appropriate site than Aspendale where effects may be compounded by urban pollution. The main cause of long-term variation of ground-level solar radiation appears to be volcanic activity as dust layers can last for several years in the stratosphere and spread over large areas of the globe.

The Division continues as the Regional Radiation Centre for the South-West Pacific (designated as Region V by the WMO) and is also the National Radiation Centre for Australia. It holds the Regional and National Standard pyrheliometric instruments for the measurement of direct solar radiation. The Division took part in the fifth International Pyreheliometric Comparison in Davos, Switzerland, in 1980. The Regional Standard is an active cavity radiometer. This type of radiometer can now measure solar radiation to an accuracy of 0.3%. A regional comparison of instruments was held at Aspendale in 1982, involving the Australian Bureau of Meteorology, the New Zealand Meteorological Service, Middleton Instruments, (Melbourne) and the Division of Atmospheric Physics.

IV CLIMATE RESEARCH

Patterns of Climatic Variation in the Southern Hemisphere

Analyses have been made of regional and hemispheric-scale patterns of variation in precipitation and temperature, with particular emphasis on Argentina, Chile, and Australia. Major influences have been identified as the Southern Oscillation (a movement of pressure between the eastern tropical Pacific and the Indonesian region) and the eccentricity of the flow around the South Pole which is sometimes more and sometimes less biased toward the Australasian as opposed to the south Atlantic sectors. The possibility of high-latitude influence on the Southern Oscillation, including lagged relationships, is being explored.

Climatic Change in Australia

Past changes in the Australian climate, both within the period of instrumental record and on paleocimatic timescales, have been analysed. Cooperative work with the Laboratory of Tree-Ring Research, University of Arizona, led to a preliminary temperature reconstruction for Tasmania from 1776 onwards, while the precipitation pattern at the time of the maximum Holocene warming (approximately 8000 years before present) has been examined. Changes in the seasonal precipitation patterns over Australia this century have been described and possible mechanisms have been identified. The most significant changes were an increase in spring, summer and autumn rainfall particularly in central N.S.W. (Figure 5) and a decrease in winter rainfall in the south-west of West Australia and on the western slopes of the Dividing Range in eastern Australia.

These studies have been applied to the question of possible regional climatic changes to be expected due to a global warming caused by the increasing concentration of carbon dioxide and other infra-red absorbing gases in the atmosphere. The principal conclusion is that the summer rainfall regime will probably extend further south and last longer, bringing increased spring, summer and autumn rainfall to large areas of Australia. Winter rainfall may decrease, especially in the south-west of West Australia, but perhaps not in Tasmania.

Impact of Climatic Change

Studies on the impact of past and possible future climatic changes on the vegetation and crop productivity of Australia have been undertaken in

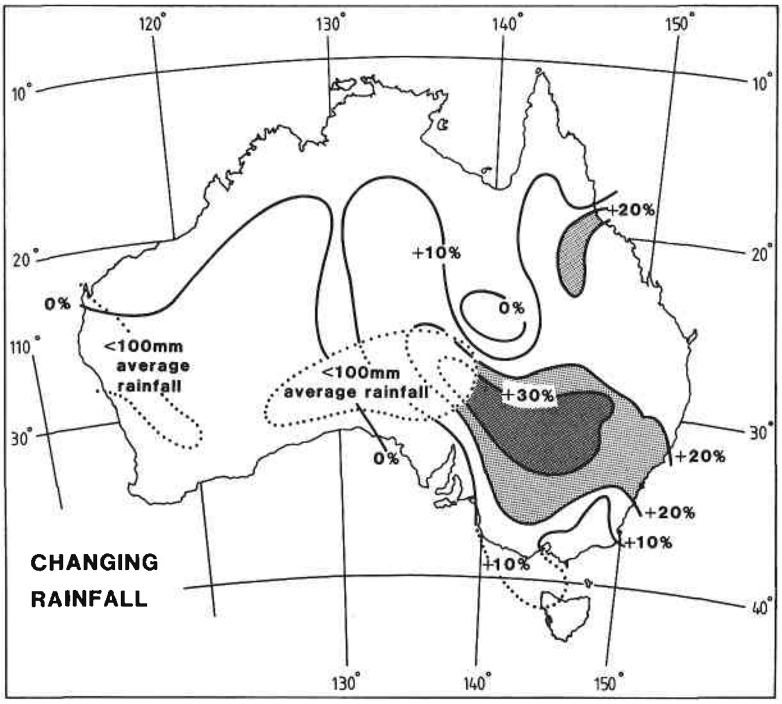

Fig.5. Illustration of the substantial changes in Australian summer half-yearly rainfall between 1913-45 and 1946-79.

cooperation with Mr. H.A. Nix of CSIRO Division of Water and Land Resources. Preliminary results using a regression model of net primary productivity in conjunction with a crude climate scenario thought to resemble the effect of a doubling of atmospheric CO_2 suggest significant increases in biomass production over most parts of Australia except the south-west of West Australia.

Solar Variability, Weather and Climate

The possibility that variations of energy radiated from the sun affect weather and climate on earth continues to be a question of wide interest with many new publications and claims subject to considerable controversy. Developments in this field have been carefully reviewed in studies for the U.S. National Academy of Science and the WMO Commission for the Atmospheric

Sciences. Many of the claims in the literature have been found to be poorly based, with little clear evidence for significant effects of solar variability on surface weather and climate. However, new and accurate satellite-based data on solar variability offer the promise of more definitive results in the near future.

Detectability of Ozone Trends

Ozone concentrations in the stratosphere are thought to be subject to the possible destructive influence of pollutants such as oxides of nitrogen and chlorofluoromethanes. At the invitation of the Environmental Studies Board, US National Academy of Sciences, and the World Meteorological Organization, studies were made of possible trends in stratospheric ozone amounts. These concluded that no statistically significant global trends have yet been detected but that satellite-based observations of the vertical distribution of ozone may enable trends due to global pollution to be detected within the next decade or so. Possible multiple causes of ozone changes will, however, make the identification of specific influences difficult.

Atmospheric Effects of a Nuclear War

At the invitation of the Australian Institute of Physics and the Australian National University, studies were made of the atmospheric effects to be expected from a major nuclear war in the Northern Hemisphere, with particular reference to effects in the Southern Hemisphere. Critical to effects in the Southern Hemisphere is the question of inter-hemispheric exchange of air and debris including smoke and dust from nuclear explosions and resulting fires. Greatly enhanced inter-hemispheric transport may result from major disturbances to the atmospheric circulation due to the absorption of solar radiation by the smoke. Debris reaching the Northern Hemisphere stratosphere would also diffuse across both hemispheres on a timescale of years. Such stratospheric injections of debris could result from the detonation of individual warheads larger than about 500 kilotonnes of TNT equivalent, from smoke plumes due to firestorms in major cities, and possibly from the convective transport aloft of tropospheric smoke clouds heated by solar radiation. Unlike earlier estimates, these considerations now suggest that major atmospheric and climatic effects may be experienced in the Southern Hemisphere due to a Northern Hemisphere war.

V ATMOSPHERIC CONSTITUENTS RESEARCH

During the past decade, there has been a worldwide increase in studies of the chemistry and composition of the atmosphere. Much of the interest in environmental quality has stemmed from urban problems. However, there has also been increased concern with atmospheric composition on regional and global scales.

The Division's interests have grown from a small stratospheric ozone program in the early 1970's to include studies of radiatively important gases (e.g. CO_2, CH_4, CO, CCl_3F, N_2O), tropospherically reactive gases (e.g. O_3, NO, NO_2), particulates, precipitation chemistry, urban pollution and constituent transport.

In their early stages, studies were observationally oriented because of lack of basic information, particularly with regard to the composition of the Southern Hemisphere atmosphere. However, the philosophy of the Division has been that the program should be based on a combination of observational, interpretive and theoretical studies. Over the past 3 years there has been increasing consideration of atmospheric composition and dynamics and the Divisional structure has allowed profitable interaction of atmospheric chemists and dynamicists.

Carbon Dioxide

Observational program. The monitoring of carbon dioxide (CO_2) in background air has continued using the Division's aircraft sampling network, the Cape Grim Baseline Station (see later) and samples collected at several sites in Antarctica. All aircraft data were brought into a form where they are internationally comparable and based on the most recent international standards, while surface-station data are being finalized in this form. A complete description of the temporal and spatial variations of CO_2 in the Southern Hemisphere mid-latitudes has been completed.

A study of the annual variation of CO_2 concentration at 3 Northern Hemisphere stations suggests that the amplitude of this variation has increased over the past 20 years. The significance of this in terms of the global carbon budget has been considered in detail. One possible interpretation is that the Northern Hemisphere seasonal biosphere has increased its annual net turnover of carbon by about 0.5×10^9 kg (approximately 10%) in recent decades.

A review of the globally available data from a number of observational programs has been carried out to establish the major features of CO_2 variation. These data have been used, in conjunction with an atmospheric transport model (see later) to obtain quantitative estimates of the major CO_2 fluxes of the global CO_2 cycle. For example, the study indicates that the present interhemispheric distribution of CO_2 relates to a net source of 5×10^9 kg per year of carbon in the Northern Hemisphere of which 2.3×10^9 kg per year are transported into the Southern Hemisphere. The equatorial oceans, by virtue of their temperature, release 1.3×10^9 kg per year of carbon into the atmosphere and high-latitude oceans take up a net amount of 4.4×10^9 kg per year. The general picture is modulated by a seasonal net exchange of approximately 6×10^9 kg per year by the global biosphere and a much smaller seasonal variation in oceanic exchange.

The potential for eddy-covariance measurements of vertical fluxes of CO_2 in the atmosphere has been critically examined. Such techniques seem very unlikely to be useful over vast areas of the global oceans.

Carbon isotopes. An active program on the stable carbon isotopes in tree-rings, started in 1975, was terminated in 1983. The carbon stored in tree-rings is derived from atmospheric CO_2 and it was hoped that historical trends in $^{13}C/^{12}C$ ratios would be indicative of atmospheric trends and thus useful in determining the degree to which biospheric carbon from deforestation and agricultural activities has contributed to the present level of CO_2 in the atmosphere.

These studies have shown considerable variability of $^{13}C/^{12}C$ between trees and that the average trend over the past 100-150 years was generally different from that described by German colleagues for Northern Hemisphere trees. Investigations in co-operation with the Research School of Biological Sciences, Australian National University, led to theoretical and observational evidence that the fractionation which was known to occur during photosynthesis is variable. It depends to a large extent on the rate of photosynthesis and in particular on environmental factors that influence the water status of the plant. It was reluctantly concluded, therefore, that trends of $^{13}C/^{12}C$ observed in tree-rings cannot be unambiguously related to atmospheric trends. These studies have, however, opened up a number of potential uses of isotopic techniques in plant physiological studies, while tree material collected in this investigation forms the basis of the developing studies in dendrochronology in Tasmania.

Observations of $^{13}C/^{12}C$ in CO_2 trapped from air at Cape Grim have continued. With the advent of more complete and competent staffing at the station, the quality of these measurements has improved markedly. The data will soon provide a measure of the current rate of non-fossil CO_2 release into the atmosphere. Seasonal and meridional variations, once defined, will be used to establish specific aspects of the carbon cycle.

In a joint study with the Glaciology Section, University of Melbourne, techniques have been developed to extract air samples trapped in Antarctic ice cores without melting the ice. By extensive measurements of a large number of gases in these samples, it is hoped to confirm the integrity of the air and provide fundamental information concerning the changes in radiatively important gases in the atmosphere over the last 2-3 centuries.

Global carbon cycle modelling. The program of modelling the global carbon cycle has five main objectives: - to predict increases of atmospheric CO_2 arising from increasing use of fossil fuel; to deduce changes in atmospheric CO_2 concentrations over the last century for comparison with corresponding climate changes; to interpret the results of the Division's carbon dioxide concentration, carbon isotope and ice-core studies; to derive the 'boundary conditions' required when using the atmospheric mixing model in more detailed studies of the carbon cycle; and to systematically investigate uncertainties in both the present and future carbon cycles.

Both the model itself and the mathematical and computational techniques involved have been developed and refined over the last three years. Additional geophysical and geochemical information has been used in calibrating and testing the model and in reducing the extent to which uncertainties in any one aspect of the model contribute to uncertainties in its predictions. The model is currently being used in a systematic study of the apparent discrepancies between direct estimates of net global deforestation based on ecosystem modelling and the amount of deforestation indicated by the recent behaviour of the carbon cycle. The model has also been involved in the interpretation of the results of the Division's program of studying carbon isotopes in tree-rings.

Atmospheric mixing modelling. The general objectives of the modelling program for atmospheric mixing are to develop a model that can describe the latitudinal and vertical distribution of atmospheric constituents on time-scales of a month or more and to use the model to quantitatively describe sources, sinks and atmospheric lifetimes of observed atmospheric constituents.

Over the last three years the main applications of the model have involved CO_2, carbon isotope ratios and CCl_3F (Freon-11); these atmospheric constituents are measured in the Division's observational programs. The model has indicated the latitudinal variation of oceanic uptake of CO_2 and has provided constraints on the amount of CO_2 arising from tropical deforestation. It will be important in interpreting the Division's observations of the global distribution of carbon-13.

Other studies have investigated the extent to which large-scale transient phenomena such as the El Nino perturb the carbon cycle. Application of the model to CCl_3F has contributed both to the refinement of the model and to investigations of discrepancies of direct estimates of the release of CCl_3F into the atmosphere. The model is being further refined by incorporation of information from the Division's dynamics program.

The Baseline Atmospheric Pollution Station

An Australian Government contribution to the WMO Background Air Pollution Monitoring Network has been the Baseline Atmospheric Pollution Station located at Cape Grim in the north-west of Tasmania. The project is jointly managed by the Department of Science and Technology and CSIRO. The Division's involvement in recent years has been via the provision of lead scientists to participate in appointment of staff, to advise on measurement, quality control, data processing and presentation associated with the station's observational and research program, the provision of technical support in construction and testing of equipment, and representation on the working group established to assist in the direction of the program.

Dr. R.J. Francey was seconded from the Division as Director of the Station, together with a Senior Technical Officer from late 1981 to December 1983. Activities of the Station are described in separate biannual reports.

Halocarbons, Nitrous Oxide, Methane and Carbon Monoxide.

Industrial and agricultural activities can cause significant changes in global atmospheric composition. Carbon dioxide is a well documented example, and the list of atmospheric trace gases increasing in concentration globally, presumably due to human activities, now includes trichlorofluoromethane (CCl_3F), dichlorodifluoromethane (CCl_2F_2), methylchloroform (CH_3CCl_3), carbon tetrachloride (CCl_4), nitrous oxide (N_2O), methane (CH_4) and possibly carbon monoxide (CO).

Current concerns about the rate of accumulation of CCl_3F, CCl_2F_2, CH_3CCl_3, CCl_4, N_2O and CH_4 in the atmosphere are based on model calculations which show that their combined climatic effect may approach the predicted global mean warming expected from a doubling of atmospheric CO_2. The resultant chlorine and nitrogen oxides, produced by the photolytic destruction of halocarbons and N_2O in the stratosphere, may also significantly reduce levels of stratospheric ozone (O_3). On the other hand increased concentrations of atmospheric CH_4 are calculated to enhance levels of stratospheric O_3. CO is not important radiatively in the atmosphere, but it significantly limits tropospheric levels of hydroxyl radicals (OH), and thus indirectly affects many other trace gases (e.g. CH_4, other hydrocarbons, CH_3Cl) whose tropospheric concentrations are, in turn, limited by reaction with OH.

The following sections detail findings from studies of atmospheric halocarbons, N_2O, CH_4 and CO, particularly during the last three years. Data have been collected on each of these species either at Cape Grim or throughout the troposphere over south eastern Australia.

(i) CCl_3F. Concentrations have risen by approximately 70% from mid 1976 to the end of 1982, or about 9% per year. The rate of increase is slowing down in response to reduced global emissions. Comparison of data collected at Cape Grim with those collected in the middle and upper troposphere over south eastern Australia show similar trends, with the aircraft data being higher, on average, by approximately 2-3 pptv. Vertical gradients of 1 pptv through the Southern Hemisphere troposphere have been suggested from model studies, due to the large-scale interhemispheric transport processes. The long term CCl_3F record suggests that maximum releases may have occurred around 1977 rather than 1974 as given in the published release data.

(ii) CCl_2F_2. Concentrations have risen by 6-7% per year since the commencement of the program. Regression analysis of the data shows that the rate of increase of CCl_2F_2 is slowing down, which is not consistent with global CCl_2F_2 releases which have increased throughout the observation period at Cape Grim. This anomaly may be resolved by acquisition of a longer data record. The absolute concentrations and trends of CCl_2F_2 observed at Cape Grim and other global observational sites indicate that the atmospheric lifetime of CCl_2F_2 is approximately 100 years.

(iii) CH_3CCl_3. Concentrations have risen by about 9% per year since the program commenced. The CH_3CCl_3 observations show significant negative curvature, consistent with a reduction of global release rates, and also an annual cycle whose amplitude and phase suggest that its cause is seasonal behaviour in atmospheric OH levels.

(iv) CCl_4. Concentrations have risen by 1.2% per year since observations began in mid-1978, which is consistent with estimated global release rates (currently 100-150 x 10^6 kg/yr) and an atmospheric lifetime of 50 years, indicating stratospheric photolysis is the major sink.

(v) N_2O. Concentrations have risen by 0.3% per year since the commencement of observations. The absolute concentration and trends of N_2O measured at Cape Grim and elsewhere have been interpreted in terms of a global N_2O source of 29 x 10^9 kg/yr, approximately 20% of which results from human activities.

(vi) CH_4. Concentrations at Cape Grim and throughout the entire troposphere have risen by 1.3% per year since observations began (Figure 6). The surface CH_4 data show an annual cycle whose phase and amplitude are qualitatively in agreement with the hypothesis that the major sink for CH_4 is oxidation by OH radicals. The global increase in atmospheric CH_4 and the observed annual cycle have been simulated with a time-dependent, global mass-balance model of the atmosphere, which incorporates seasonally varying OH levels and a CH_4 source of 550 x 10^9 kg/yr, whose anthopogenic component (approximately 50%) is growing at 3-4% per year.

(vii) CO. Concentrations observed at Cape Grim do not appear to have changed significantly over the observational period. A longer data record, with increased frequency of observation, may reveal a trend. Comparison of observations from a number of global sites suggests that the concentrations observed in the Northern Hemisphere are 2.5 times higher than those observed in the Southern Hemisphere. CO concentrations at Cape Grim show an annual cycle similar in phase and amplitude to the CH_4 cycle described above, suggesting a common cause, namely the seasonal influence of atmospheric OH radicals.

Nitrogen Gases in the Lower Atmosphere and their Production in Soil.

Nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O) and ammonia (NH_3) all play an important role in the chemistry of the lower atmosphere. The cycles of these gases are strongly influenced by their production or removal in soils and plants.

In the troposphere, the energy for many chemical processes is derived from the oxidation of carbon monoxide, hydrocarbons and organic compounds to carbon dioxide and other products, along with the absorption of visible and near-visible ultraviolet radiation by nitrogen dioxide, ozone and some other trace species. Tropospheric chemistry is dominated by reactions of hydroxyl and hydroperoxyl radicals initially formed from water vapour and excited atomic oxygen, itself generated by the photodissociation of ozone. Nitric oxide and nitrogen dioxide both have a regulatory role in this chemistry.

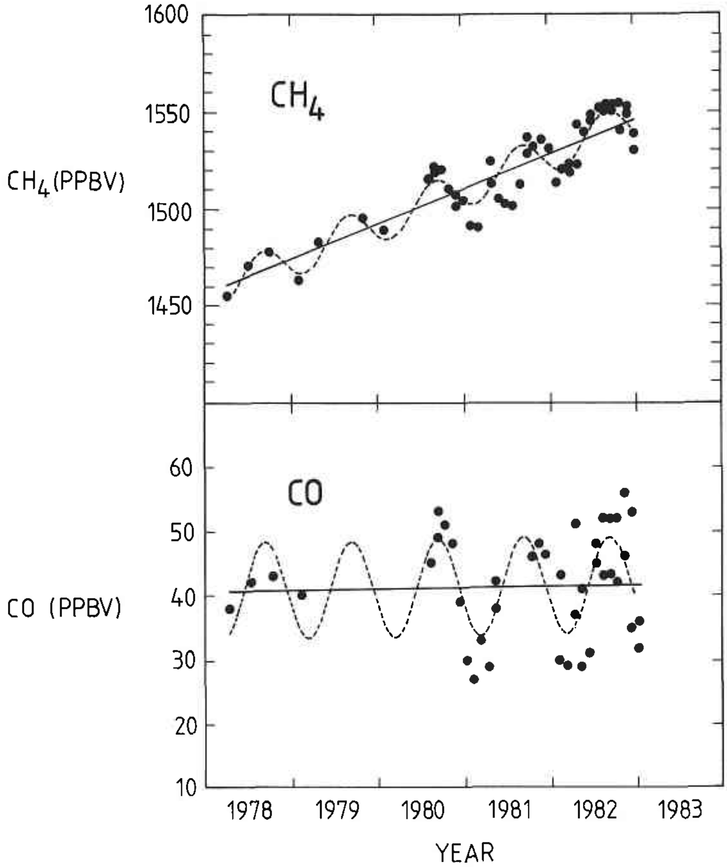

Fig.6. Monthly mean concentrations of methane and carbon monoxide at Cape Grim. Dashed and solid lines show linear regressions with and without a function to approximate observed annual cycles.

When the nitric oxide concentration is low, ozone is consumed, when it is high, ozone is produced. The concentration of hydroxyl radicals is regulated by nitric oxide and carbon monoxide.

During the last three years, both field and laboratory studies have been initiated on the soil/atmosphere exchange of NO and NO_2. Measurements have been carried out over a grazed pasture at the Victorian Department of Agriculture Research Station at Rutherglen, Victoria. Measurements were made by placing a stirred chamber over a site (0.8m x 0.8m) and measuring the change of NO and NO_2 concentration in the chamber. The exchanges observed can be explained by the presence of a constant exhalation of NO from a soil site accompanied by an opposing concentration-dependent uptake. No persistent flux of NO_2 was detectable. The uptake velocity for NO_2 was on average 3 to 5 times larger than for NO. Laboratory studies have been carried out on NO production in soils as joint work with the Department of Meteorology, University of Stockholm. The studies indicated, for example, that at least 90% of the NO production in the soil was of biological origin and that production of NO was at least a factor of 10 larger in anaerobic conditions than in aerobic conditions. A simple physical model has been designed to aid the interpretation of these measurements and to provide the basis for more elaborate models of soil/atmosphere exchange of NO applicable to the field situation.

Nitrous oxide (N_2O) is also produced by soil and aquatic microbes as well as in some combustion processes. It is of interest since it is, via chemical reactions, the source of reactive nitrogen oxides in the stratosphere which have a major influence on the global ozone balance and also since it is a significant absorber of terrestrial infrared radiation in the atmosphere and may therefore contribute to change in the surface temperature and the climate of the earth.

Analysis of air samples from Cape Grim show an increase in nitrous oxide over the period 1978-1982 of the order of 0.3 ppb/yr as a linear trend. Other increases have been observed by US workers at Samoa, the South Pole and in the Northern Hemisphere. This increase in atmospheric N_2O could be due to either an increase in strength of natural sources such as soils and oceans or a decrease in the stratospheric sink, or both. It also has been suggested that an increase may have come about from man's fossil fuel combustion or agricultural activities.

Stratospheric Nitrogen Oxides Experiment

As mentioned in the previous triennial report, a major project was undertaken on nitrogen oxides and other trace gases in the Southern Hemisphere stratosphere. Scientists from York University and the Atmospheric Environment Service of Canada and several Australian laboratories participated.

In the stratosphere, short-wave ultraviolet radiation dissociates molecular oxygen and forms a constant source of atomic oxygen and subsequently ozone. Trace gases from the lower atmosphere, including nitrous oxide, halocarbons (both natural and man-made) and water vapour, dissociate in the stratosphere forming reactive species, which react with the atomic oxygen and ozone, thereby maintaining an equilibrium ozone concentration in the stratosphere.

Recent concern about the ozone layer has been based on the notion that man may be increasing the concentration of these trace gases or reactive species in the stratosphere and thus ultimately may reduce the equilibrium ozone concentration. Balloon-borne measurements of ozone, nitrogen compounds and other trace constituents in the stratosphere have been used to verify and, in some cases, question parts of the complex reaction schemes used in the computer-based numerical models of the stratosphere.

There were vertical and latitudinal variations in the relative proportions of NO, NO_2 and HNO_3, with substantial increase in the total towards high latitudes. Unusual profiles of aerosol, CCl_3F and NO were observed at Alice Springs and Mildura.

Comparison of these observations and modelling results showed good agreement for profiles of O_3, N_2O, NO and NO_2. However the models predict too little NO_y ($NO_y = NO + NO_2 + HNO_3$) below 22 km and fail to reproduce the latitudinal variability of NO_2 and HNO_3. The models accurately simulate the conversion of N_2O to NO_y and the partitioning of $NO:NO_2:HNO_3$. Comparison of N_2O and CCl_3F loss in the stratosphere suggests a more rapid loss of CCl_3F in the lower tropical atmosphere than is calculated by these models. This factor may have some influence on the accuracy of predicted O_3 depletion by CCl_3F.

Some comparisons of observations and modelling results have indicated inaccuracies in simulation of, for example, radiation transmission, transport processes in the lower stratosphere and winter-time chemistry at high latitudes. A comparison of the Southern Hemisphere data set with similar data from the Northern Hemisphere is underway.

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 exhaust emissions from motor vehicles. A survey of the Melbourne smog situation has been undertaken by means of an aircraft equipped to measure the relationship between the concentration of precursors and the resultant concentration of ozone, and various meteorological parameters.

The survey showed that the emissions from the central and western suburbs rarely if ever gave rise to smog events over the metropolitan area.

An event is a day during which the average hourly ozone concentration exceeds the acceptable level of 120 parts per billion by volume. On smoggy days the winds tended to carry all emissions toward the west leading to events in the rural sectors to the north-west and south-west of the city. On average these events occurred about eight times a year, some events possibly affecting the same location more than once per year. On an average of about four occasions per year part of the metropolitan area (usually the city and the suburbs to the north and west of the city) experienced a smog event, the source of which was emissions from suburbs to the east and south-east of the city, these emissions being carried south-west over Port Phillip Bay then to the north by the bay breeze which sets in at about noon (Figure 7).

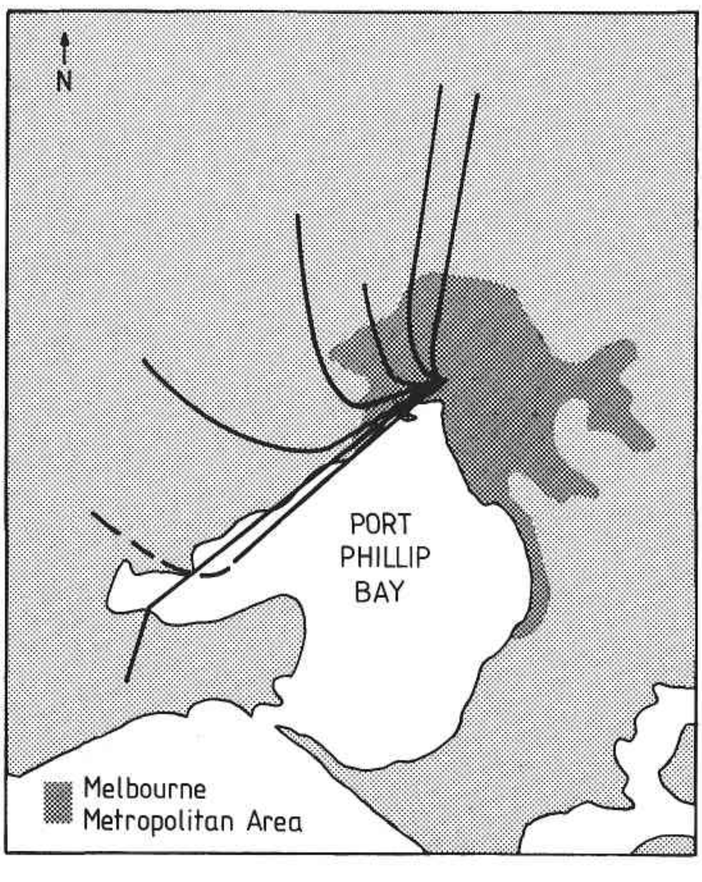

Fig.7. Paths of emissions from the central business district on eight smoggy days (1979/1980).

The wind trajectories imply that the emissions from the Newport D power station are incorporated in the general emissions which affect the rural area but on only two occasions per year, on average, is the Newport D plume incorporated in the emissions which give rise to metropolitan events.

Because of the emphasis which this survey placed on the emissions from the eastern suburbs of Melbourne a survey has been made of the hydrocarbon composition of these emissions. By comparing the hydrocarbon composition of motor vehicle exhaust and traffic emissions with that of ambient air downwind of the eastern suburbs, it has been shown that 55-65% of the hydrocarbons from this area are from motor vehicle exhaust, 30-35% from evaporative losses from motor vehicles and 5-10% from non-motor vehicle sources. Of particular interest was the finding that about half of the evaporative losses from motor vehicles take place while the vehicles are moving - a rather unexpected source of emissions and one which is not part of the test for compliance of vehicles with the present Australian Design Rules.

Smog chamber experiments are now proceeding with the aim of simulating the behaviour of the emissions from the eastern suburbs.

VI MISCELLANEOUS

Instrumentation developed in support of basic research at the Division has sometimes an unexpected and useful impact in unrelated commercial and domestic areas:

Measuring knitting yarn: Opto-electronic counters used for sensing the rotation of anemometers have been adapted for measuring the yarn length used by circular knitting machines. The instrument allows for the accurate sizing and repeatability of production in, for example, sock manufacture. The low-cost yarn sensor may be readily attached to standard knitting machines. Patentability of the device is under review.
Forestalling oil-painting damage: An instrument for measuring the ultraviolet light in solar radiation has been developed primarily for medical research, for example into sunburn and skin cancer, and for agricultural research, for example into eye diseases of cattle. However, it is also used in the National Gallery of Victoria to measure levels of UV potentially harmful to oil paintings.

Improved TV reception: A very low-noise, wide band-width amplifier developed for meteorological balloon telemetry applications has been found to offer significant performance advantages over existing amplifiers, when used in TV masthead applications at fringe-signal sites. The amplifier is being manufactured by a Melbourne company.

VII PERSONNEL, AFFILIATIONS

Awards

Dr. A.B. Pittock was awarded a Certificate of Commendation by the U.S. Federal Aviation Administration for service to the U.S. Government and Aviation Industry.

Transfers

Dr. A.D. McEwan, Assistant Chief of the Division, was appointed Chief of the CSIRO Division of Oceanography.

Dr. P.J. Webster was appointed Professor of Meteorology, Pennsylvania State University, U.S.A.

New Appointment

Dr. I.G. Enting joined the Division to work on carbon cycle modelling.

Secondments

Dr. R.J. Francey and Mr. I.D. Helmond were seconded for two years to the Cape Grim, Tasmania, Baseline Air Pollution Station of the Department of Science and Technology as Director and Senior Technical Officer, respectively.

Dr. G.W. Paltridge served as Executive Director, Petroleum Industry Environmental Conservation Executive, for 1 year.

Death

Mr. A.J. Troup died in 1983 having served CSIRO since 1949.

Retirements

Six long-serving members of the Organization have retired from the Division: Mr. N.E. Bacon (appointed 1956), Mr. P.D. Berwick (1963), Dr. A.J. Dyer (1954), Mr. L.F. Evans (1943), Dr. R.N. Kulkarni (1961) and Mr. I.C. McIlroy (1949).

Affiliations

Mr. I.G. Bird:- Member, National Commission for Antarctic Research, Sub-committee on Meteorology, Australian Academy of Science (AAS).

Dr. R.J. Francey:- Member, Department of Science and Technology (DST) Baseline Air Pollution Station (BAPS) Working Group.

Dr. P.J. Fraser:- Member, Environmental Law Committee, International Law Association; member DST BAPS Working Group; member, National Health and Medical Research Council Working Party on chlorofluorocarbons and alternative aerosol propellants.

Mr. I.E. Galbally:- Member, Advisory Committee SCOPE UNEP International Nitrogen Unit; member, National Committee on the Environment, AAS; member, DST BAPS Working Group; member, International Ozone Commission, International Association of Meteorology and Atmospheric Physics (IAMAP); associate editor of Journal of Atmospheric Chemistry.

Dr. J.R. Garratt:- Member, editorial board, Boundary Layer Meteorology; member editorial committee, Quarterly Journal of Royal Meteorological Society; Chairman WMO Group of Rapporteurs on Boundary Layer Problems.

Dr. P.C. Manins:- Member, Latrobe Valley Air-shed Study Working Group; Convenor LVASS Data Interpretation Group.

Dr. G.W. Paltridge:- Secretary, International Radiation Commission, IAMAP; Chairman, National Committee for Atmospheric Sciences, AAS.

Dr. G.I. Pearman:- Member, WMO Commission of Atmospheric Science, Group of Rapporteurs on Carbon Dioxide and the Carbon Cycle; member, WMO Commission for Instruments and Methods of Observation, Working Group on Instruments and Methods for Environmental Pollution Measurement; member, Commission on Atmospheric Chemistry and Global Pollution, IAMAP; member, DST BAPS Working Group.

Dr. A.B. Pittock:- Member, Scientific Advisory Committee to the U.S. Federal Aviation Administration's High Altitude Pollution Program; member, Working Group for Solar-Terrestrial Relations, International Commission for Meteorology of the Upper Atmosphere, IAMAP; member, National Committee for the Environment, National Committee for Atmospheric Sciences and sub-committee on the World Climate Research Program, AAS; panel member, Study on Sun, Weather and Climate, Geophysics Research Board, U.S. National Academy of Science.

Dr. C.M.R. Platt:- Member, International Radiation Commission, IAMAP; member, DST BAPS Working Group.

Dr. R.A. Plumb:- Member, International Commission for Dynamical Meteorology, IAMAP.

Dr. G.L. Stephens:- Member, Program Committee IAMAP Clouds and Radiation Group; Co-convenor, Working Group on Intercomparison of Radiation Codes for Climate Models, IAMAP; associate-editor of Journal of Atmospheric Science and of Monthly Weather Review.

Dr. G.B. Tucker:- Chairman, National Committee for GARP, Australian Academy of Science; member, Joint Organizing Committee for FGGE; Chairman, National Drifting Buoy Programme Committee; Vice-President, Joint Organizing Committee, GARP; member, JSC GARP/WCRP; Chairman, Advisory Group to EPA, Victoria on Melbourne Air-Shed Study; member, Latrobe Valley Air-Shed Study Steering Committee; member, Australian National Committee on Atmospheric Science, AAS.

Mr. E.K. Webb:- Member, International Association of Geodesy, Special Study Group on Electromagnetic wave propagation and refraction in the atmosphere.

Dr. P.J. Webster:- Member, editorial board of Pure and Applied Geophysics.

Overseas Visits

Dr. I.J. Barton spent 15 months at the Department of Atmospheric Physics, Oxford University, analysing data from the NIMBUS 5 satellite.

Dr. P.J. Fraser spent 12 months at NOAA, Boulder, U.S.A. working on the Geophysical Monitoring for Climate Change programme.

Dr. J.S. Frederiksen spent 8 months as Visiting Fellow at NCAR, Boulder, U.S.A. and 3 months as Crawfoord Fellow at the University of Stockholm in research on large-scale atmospheric processes.

Mr. I.E. Galbally visited the Department of Meteorology, University of Stockholm for 5 months studying emissions of nitrogen gases to the atmosphere.

Dr. J.R. Garratt spent 12 months as Visiting Scientist, NCAR, Boulder, U.S.A., studying small-scale atmospheric processes.

Dr. R.A. Plumb spent 8 months as Visiting Scientist, geophysical fluid dynamics program, Princeton University, U.S.A.

Dr. B.L. Sawford spent 12 months on turbulent dispersion research at the Department of Applied Mathematics and Theoretical Physics, Cambridge University.

Dr. G.L. Stephens spent 16 months as Visiting Faculty Member, Department of Atmospheric Sciences, Colorado State University on earth radiation budgets measured by satellites, and associated studies.

Dr. G.B. Tucker spent 9 months as Senior Visiting Fellow at CIRES, NCAR, Boulder, U.S.A. concerned with large-scale responses of the atmosphere to variations of incident solar radiation.

Dr. P.J. Webster spent 9 months as Visiting Scientist, geophysical fluid dynamics programme, Princeton University, U.S.A.

In addition, the following made shorter visits (1-8 weeks) for such purposes as attending conferences, delivering lectures, and visiting research centres: Dr. P.G. Baines, Mr. A.C. Dilley, Dr. P.J.B. Fraser, Mr. I.E. Galbally, Dr. J.R. Garratt, Mr. P. Hyson, Dr. G.W. Paltridge, Mr. G.R. Patterson, Dr. G.I. Pearman, Dr. A.B. Pittock, Dr. C.M.R. Platt, Dr. R.A. Plumb, Dr. W. Shepherd, Dr. G.L. Stephens, Dr. G.B. Tucker, and Dr. P.J. Webster.

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