CSIRO

Division of Atmospheric Research

Research Report 1985 – 1988

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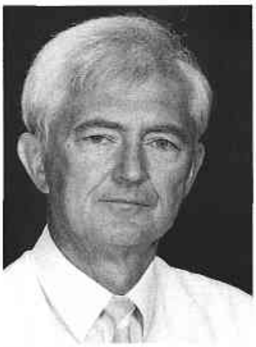
Contents

Foreword



The Chief of the CSIRO Division of Atmospheric Research, Dr G. B. Tucker

This research report is being issued at an auspicious time. The current popular and world-wide interest in atmospheric science is unique. A general awareness of the precious nature of our environment not only encompasses important specific topics such as acid rain, air quality and stratospheric ozone, it is now firmly focussed on climate — the synthesis of all atmospheric studies.

Over the last three years the Division of Atmospheric Research has experienced a remarkable increase in morale and in resources. Practically all the increased funding is from external sources and has been due to the enthusiastic advocacy by members of the Division of the skills resident here and the scientific achievements that contribute strongly to national objectives. In the past eighteen months increased external funding has significantly exceeded further cuts in Treasury funding and the growth being experienced at the Division contrasts markedly with the overall trend within CSIRO. A major expansion, of course, has occurred in greenhouse type research. However, this has been paralleled by strong scientific advances in drought prediction research, in aspects of remote sensing and in the application of laboratory, field, theoretical and computing skills to problems of atmospheric pollution.

The Division has been strongly involved in many national and international programs and is generally regarded as a leading agency in climate research, in atmospheric chemistry on both regional and global scales and in boundary layer studies. This report details work in these areas and describes other research achievements between 1985 and 1988.

Strong support for this resurgence of atmospheric science and the role of the Division in solving problems of major national relevance has been shown by many who are involved in one way or another with our activities. These include the Director of the Institute of Natural Resources and Environment; the Divisional Advisory Committee; the Australia and New Zealand Environment Council and associated State agencies; several Government departments, particularly the Department of Arts, Sport, the Environment, Tourism and Territories; the Commission for the Future and the Australian Conservation Foundation. Fair and sympathetic reporting from the media has contributed to the new sense of purpose and self-esteem that has spread throughout the Division.

It is a great pleasure to acknowledge the fine spirit and pride in achievement shown by all staff members.

G. B. Tucker
Chief of Division

November 1989

Overview

While the thrust of the Division's research effort has remained the same, there has been a redefinition of the four major research programs. Each program is made up of a number of research projects and the projects listed are current for July 1988. The new programs and component research projects are:

Global Atmospheric Change
Research seeks to discover why the chemistry of the atmosphere is changing, how it will change in the future and how our climate is influenced by these changes. The aim is to provide a predictive capability of atmospheric and climatic change and to put this in a specific Australian perspective.

- The mechanisms and causes of increases in non-reactive trace gases (carbon dioxide, methane and chlorofluorocarbons) in the global atmosphere
- Scientific support for the Cape Grim Baseline Atmospheric Pollution Station (CGBAPS)
- Chemical, physical and biological mechanisms regulating reactive gases and aerosols in the global atmosphere
- Studies of the dynamics and physics of global and regional climate change
- Studies of dynamical and physical mechanisms producing anomalous atmospheric circulations
- Climate impact and assessment

Atmospheric Pollution and Bushfire Meteorology
This program studies factors which influence air pollution and bushfires. The focus is on identifying sources of pollution and understanding the way in which it is formed, transported and dispersed. The aim is to assist industry and regulatory bodies which are concerned with atmospheric pollution and the implementation of control strategies.

- Theoretical and experimental studies of turbulent dispersion in the atmospheric boundary layer
- Air quality dynamics: research and applications
- Regional studies of visibility reducing aerosols and oxidant precursors in the Latrobe Valley
- Bushfire meteorology research

Remote Sensing
A precise understanding of the way solar radiation interacts with the atmosphere is essential to our understanding of many physical processes which determine the nature of our weather and climate. Remote sensing techniques are used to collect information about the earth's atmosphere, oceans, land and ice surfaces. The aim is

to use our improved understanding of these physical processes to provide accurate information for the management of the natural environment.

- Satellite data applications
- Commercialisation of CSIDA
- New instruments for meteorological satellites
- Development of new lidar technology for atmospheric research

Water Resources

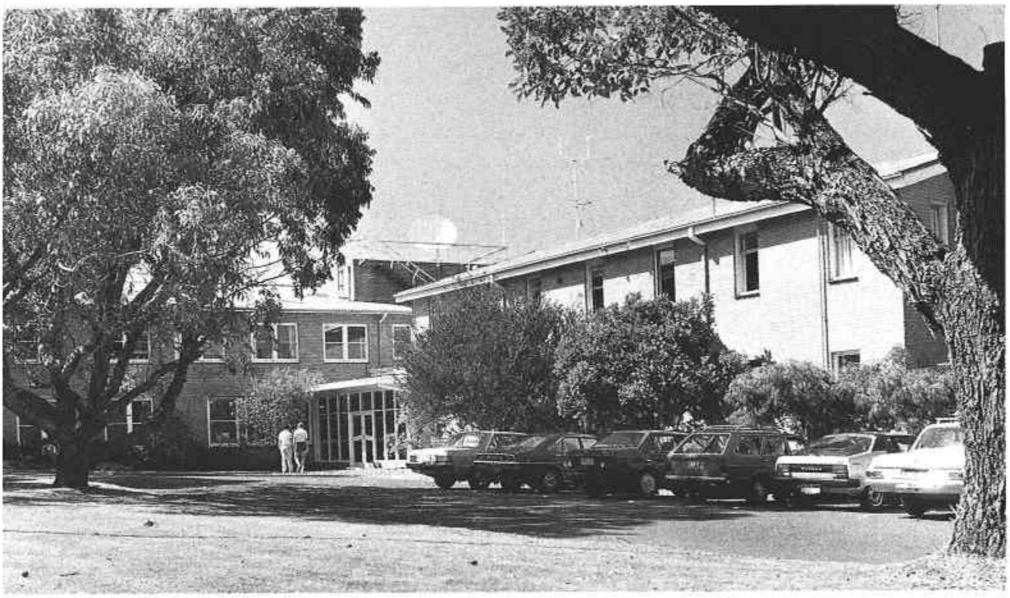
The program focuses on the way in which regional and global weather and climate processes influence the water budget. The aim is to provide practical means of forecasting droughts and to carry out research to improve our understanding of storms and rain-bearing systems.

- Drought studies
- Dynamics of mesoscale convective systems
- Surface moisture impact on climate
- Winter storms and cloud seeding, quantitative precipitation forecasting

Staff and finance

The Division of Atmospheric Research has some 115 staff, approximately two-thirds of whom are Research and Experimental Scientists. Expenditure in each of the financial years 1985–86, 1986–87 and 1987–88 was $6.2 million. In 1985–86 the non-appropriation funding was 3.5% of the total expenditure, but by 1987–88 this had risen to 11%. The Division is steadily increasing its level of funding from external sources and expects these sources to provide over 30% of its budget within two years.

The Division of Atmospheric Research



External funding

Project	Lead scientist	Grant
Dept of Foreign Affairs 1985–86 *Climatic effects on Australia of a nuclear war in the Northern Hemisphere*	B. Pittock	$140 000
Department of Science/Bureau of Meteorology 1985–88 *Baseline Air Pollution Station*	G. Pearman	$420 000
EPA(V) 1987–88 *Ambient organics*	I. Galbally	$15 000
EPA(V) 1987–88 *Non-methanic hydrocarbon study*	I. Galbally	$5 000
MMBW 1987–88 *Cloud seeding consulting contract*	A. Long	$230 000
MMBW 1987–88 *CSIRO F27 hire*	A. Long	$60 000
NERDDC 1987–88 *Meridional carbon isotope variations*	R. Francey	$13 500
NERDDC 1985–88 *Latrobe Valley Aerosol Visibility Study*	G. Ayers, J. Gras	$81 000
SEC(V) 1986–88 *Research Fellowship*	B. Sawford	$140 000
Victorian Department of Conservation, Forests and Lands (NBRU) 1987–88	T. Beer	$4 000
Wheat Industry Research Council 1986–88 *Gaseous nitrogen emission from irrigated wheat in South Australia*	I. Galbally	$20 000
Revenue earned by the Division		
Anemometer calibrations 1986–88		$35 000
CSIDA Images 1986–88		$50 000
Mass spectrometry analysis 1987–88		$5 000
Workshop/Conference funding:		
AVHRR Workshop 1986–87 COSSA		$5 000
Bureau of Meteorology		$10 000
CSIRO (Groundwater Research)		$3 000
Asia Australia Association via COSSA		$2 000
GAGE Meeting 1986–87 Bureau of Meteorology		$3 000
Aerosol Association of Australia		$1 000
Greenhouse 87 sponsorship 1987–88		$18 500

The Divisional Advisory Committee

In a move to ensure the Division's accountability and to strengthen the Division's support from outside CSIRO, Dr Tucker decided in 1983 to invite a number of prominent figures to serve on a Divisional Advisory Committee. The Committee meets twice a year and advises the Chief on policy and other matters. It also has a very important role in identifying the interests of the Australian community that may be furthered by the Division's research as well as suggesting the best way to make this work known to interested persons and organisations.

In July 1988 the Advisory Committee consisted of:

Mr Hal Holmes, Chairman
Chairman (retired), Monsanto Australia Limited

Mr Richard Llewelyn,
Manager, Research and Development, State Electricity Commission of Victoria

Mr Mike Lodge,
Deputy General Manager (retired), Board Member, Woodside Offshore Petroleum Pty Ltd

Dr Ian McPhail,
Director-General, Department of Environment and Planning, South Australia

Mr Alan Rainbird,
Deputy Secretary, Commonwealth Department of Aviation

Dr Brian Tucker,
Chief of Division of Atmospheric Research

Mr Bob Chynoweth, Observer
M.P., Federal Member for Dunkley

Dr Willem Bouma, Secretary to the Committee
Division of Atmospheric Research

Highlights 1985 – 1988

The Atmospheric Pollution and Bushfire Meteorology Program has shown significant progress in all areas. In particular, a new laboratory facility (a large convection tank) is in the process of being constructed and installed. Amongst other highlights for this program was the successful completion of the Latrobe Valley Air Shed Study in which CSIRO collaborated with the State Electricity Commission of Victoria (SECV) and the Environment Protection Authority of Victoria (EPAV). Theoretical studies on plume dispersion in the convective boundary layer compliment the Latrobe Valley field work. An offshoot of the Airshed Study, a National Energy Research, Development and Demonstration

Council (NERDDC) supported project on visibility problems and ozone precursors in the Valley, was carried out by the Division's atmospheric chemists.

There have also been several developments relating to the Global Atmospheric Change Program. These include significant scientific achievements in trace gas studies such as improved precision in CO_2 measurement and the successful analysis of air trapped in Antarctic ice, contributions to the understanding of the newly discovered "ozone hole" and a burgeoning gas container project which has commercial implications. A scenario of climate change for Australia was developed to assist the preparation for the Greenhouse 87 Conference which is referred to below.

An exciting project in the Remote Sensing Program was the design and development of a prototype atmospheric pressure scanner while collaboration with the Rutherford Appleton Laboratory in the UK continued on the development of the Along Track Scanning Radiometer. A novel activity for the Division has been to provide the motivation and the business plan for a new company to design, engineer and market satellite reception and analysis systems. Commercialisation of products from satellite data continues to bring revenue to the Division.

The drought component of the Water Resources Program has been highly successful scientifically in establishing an association between continental scale drought and two different sea surface temperature anomaly patterns in the Pacific Ocean. Indeed, a novel theoretical approach is being developed to determine that pattern of anomalous sea surface temperature which produces the largest response in the atmospheric circulation. A second feature of this program has been the Division's involvement in field experiments on mesoscale weather phenomena such as convective storms over northern Australia and frontal systems over south-eastern Australia.

During 1987 the Division put a great deal of effort into organising the Greenhouse 87 Conference. The two major objectives were:

- to have experts in the various potential impact areas assess the impacts of climate change of the kind possible due to greenhouse warming.
- to communicate to the wider scientific and engineering community the current status of the greenhouse theory.

About 90 scientists and engineers took up the challenge early in 1987 and prepared 57 papers for presentation at the meeting. The papers were of a high standard and, after refereeing and selection, they were used to produce the Greenhouse 87 Conference Proceedings, which were almost ready for publication by the end of the reporting period.

Global Atmospheric Change

Introduction

Changes in the chemical composition of the atmosphere are occurring both regionally and globally. Locally these changes have effects on visibility and the quality of the air we breath. At a global level there is now strong evidence that these changes are likely to bring about significant climatic modifications as a result of the greenhouse effect. Some will be beneficial, others will not.

Reliable predictions of these changes will be of great benefit to the Australian community. This requires an understanding of why the chemistry of the atmosphere is changing, how it will change in the future and how the climate system, at both the global and regional level, is influenced by these changes.

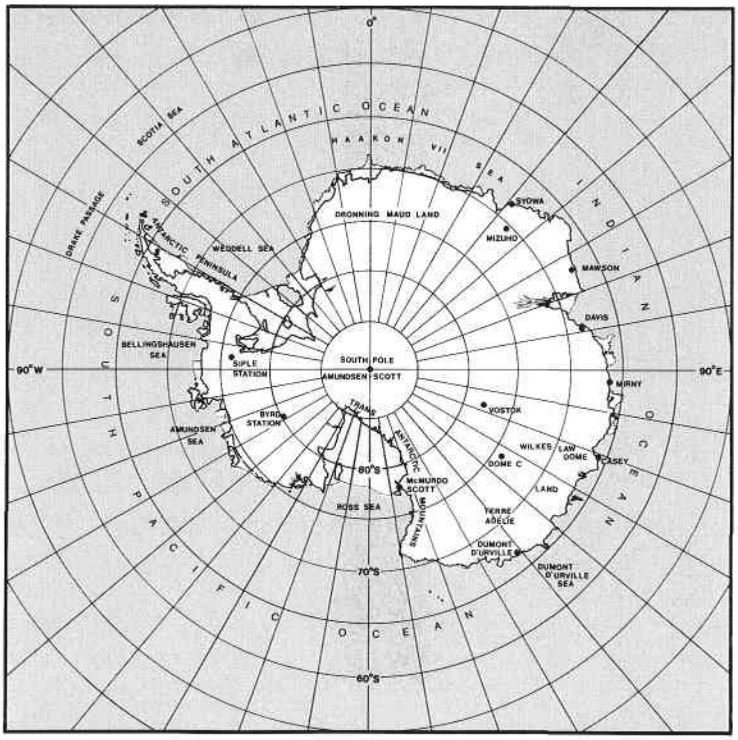
The objectives of the Global Atmospheric Change Program are to predict and understand the mechanisms responsible for alterations in the chemical and physical character of the atmosphere. Projects involve a combination of theoretical numerical modelling and observations which will improve the understanding of the budgets of key climatically important trace gases and aerosols.

Carbon dioxide

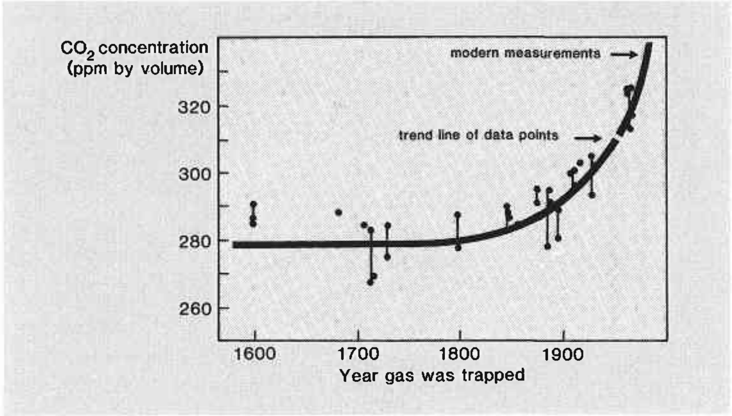
Confident predictions of how future carbon dioxide emissions will affect the concentration of this gas in the atmosphere rely on an accurate model of carbon dioxide pools and their interactions. For accurate modelling the carbon dioxide concentration prior to 1850 must be known. It was at this time that industrialization and forest felling began to have an impact.

Air bubbles trapped in polar ice from as long ago as the 17th century have been analysed by Division scientists in collaboration with scientists from the Australian Antarctic Division. It has been discovered that, prior to 1800, the carbon dioxide concentration was essentially constant at about 280 ppm.

To carry out the analysis, ice which has been drilled from the Antarctic is crushed under vacuum. The released air is then dried and condensed in a trap cooled by liquid helium, and transported to the CSIRO laboratories. Gas chromatography is used to determine the abundance of carbon dioxide as well as nitrous oxide and methane.



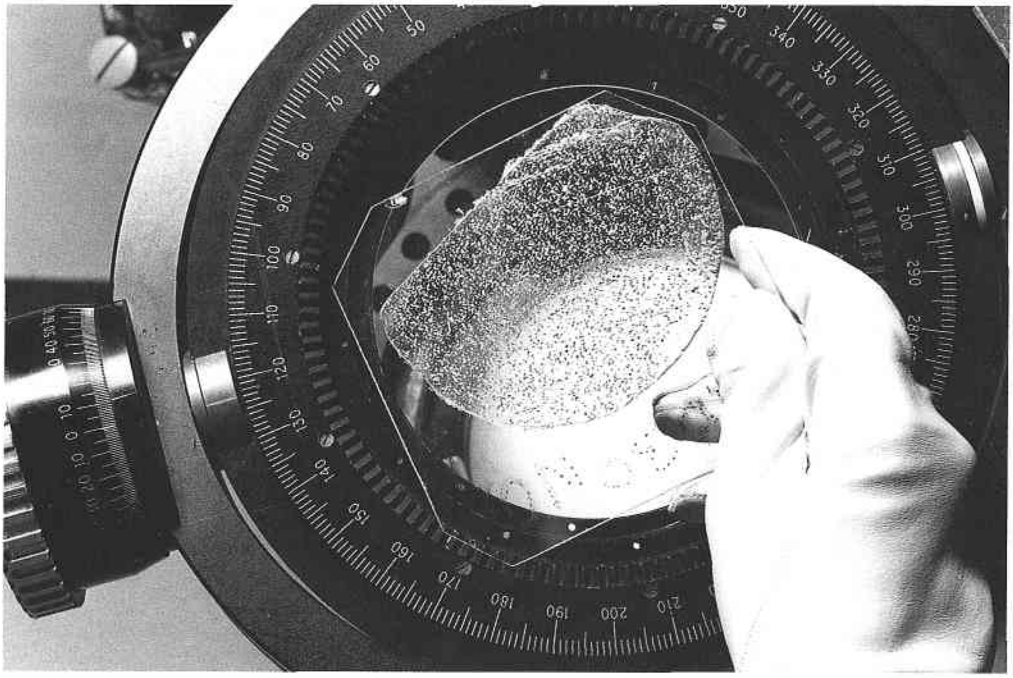
Map of Antarctica showing major features, ice-coring sites and stations



Carbon dioxide concentrations determined from air trapped in Antarctic ice-cores

Impact of plants on carbon dioxide

The Division of Atmospheric Research operates a high quality sampling network measuring the carbon-13/carbon-12 isotope ratio in atmospheric CO_2 from clean air sites. This is used to identify the portion of the CO_2 which has experienced photosynthesis in land plants, including that from fossil fuels. An unanticipated bonus from this project, which is funded by NERDDC and has logistic support from CGBAPS (Cape Grim Baseline Air Pollution Station), NOAA/GMCC (Geophysical Monitoring For Climate Change) and the Australian Antarctic Division, is the first reliable global data on the oxygen-18/



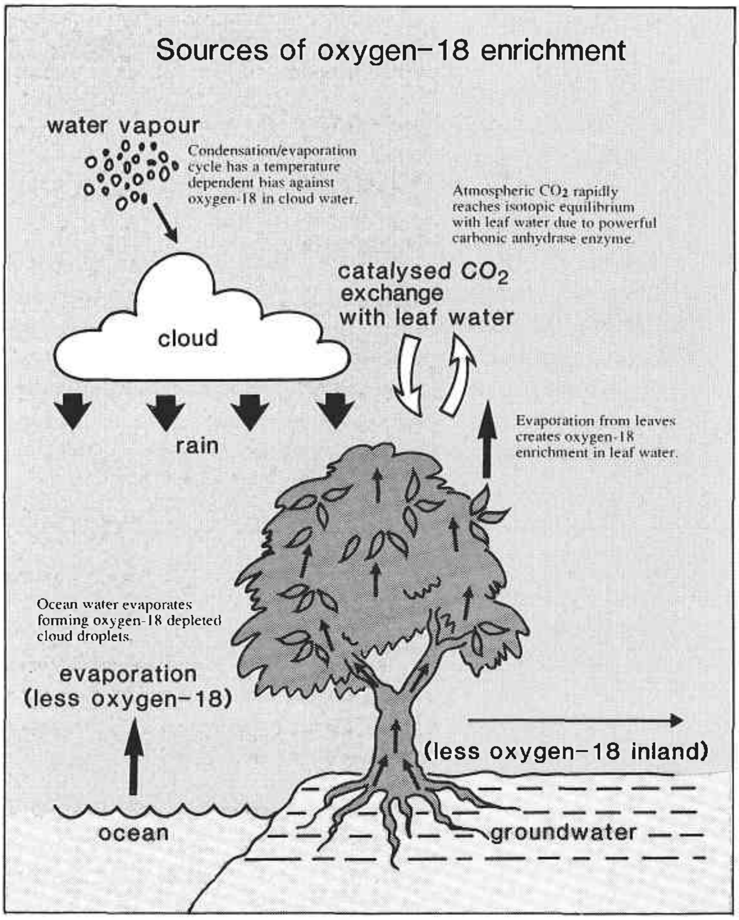
A cross-section through an ice-core from Law Dome, Antarctica.

oxygen-16 isotope ratio. It has been found that the oxygen isotope ratio exhibits strong systematic behaviour with both latitude and season as well as with the El Niño – Southern Oscillation phenomenon.

The most likely explanation is that this is also due to the action of green plants, 90% of which grow in the tropics and the northern hemisphere. Measurements indicate that between 30% and 50% of the total atmospheric CO_2 interacts with leaf water each year. It is dissolved and oxygen atoms are exchanged with the water before the carbon dioxide is again released. While within the plant, the CO_2 molecule encounters the enzyme carbonic anhydrase which ensures rapid exchange of one of its constituent oxygen atoms for an oxygen atom from one of the plant's water molecules.

Both the signature of the ground water oxygen-18 content (lower from the poles and continent interiors) and the shift of the ground water oxygen-18 due to evaporation from leaves, is reflected in the atmosphere carbon dioxide oxygen isotope values. The effects are most marked in the northern hemisphere.

At a time when serious questions are emerging about the way fossil fuel carbon dioxide is being removed from the atmosphere, the research is providing a fresh look at a gross exchange aspect of the carbon cycle which has not previously been observed. Variations in this data carry information on zonally averaged plant activities. At the least, the oxygen isotope ratio in CO_2 promises to be an unusual tracer of atmospheric transport.



Sources of oxygen-18 enrichment

The greenhouse effect

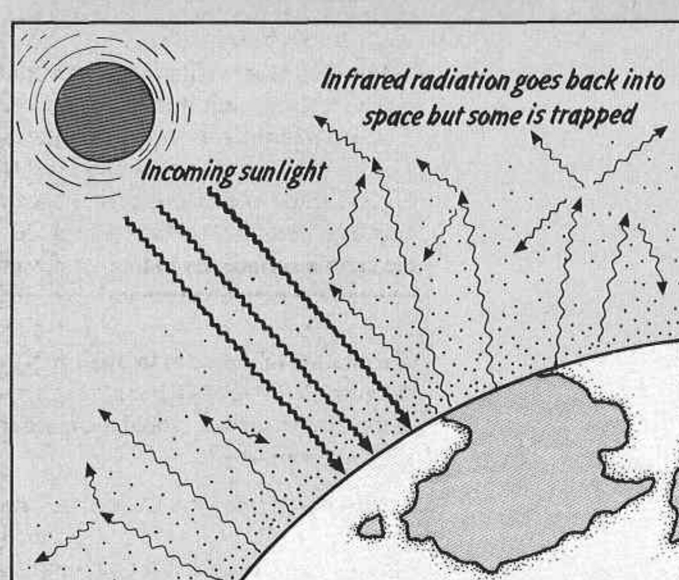
There are a number of gases in the earth's atmosphere which are able to intercept infrared radiation. The principal gases are water vapour and carbon dioxide and both have a similar effect on the radiation balance of the atmosphere. They allow incoming (visible) solar radiation to pass through unhindered, but absorb a significant fraction of the outgoing infrared radiation emitted by the earth's surface. Even though the radiation lost to space is still equal to the radiation received from the sun, the combined effect of the radiatively active gases and clouds is to increase the surface temperature of the earth in order to balance the incoming solar radiation. Without this *greenhouse effect*, the average temperature of the earth's surface would decrease from its present level of 15°C to about –18°C.

In recent years the term greenhouse effect has been used to describe the global warming expected as a result of man-induced changes to concentrations of atmospheric trace gases which absorb in the infrared.

Greenhouse gas	Annual increase	Major sources
Carbon dioxide	0.4%	fossil fuels, deforestation
Methane	0.8%	livestock, rice paddies, mining
Nitrous oxide	0.3%	biomass burning, fossil fuel combustion
Chlorofluorocarbons	5–10%	industrial applications

Over the next 40 years it is thought that the greenhouse effect will lead to:

- global warming of 1.5 to 4.5°C.
- world-wide changes in climate.
- changes to rainfall distribution, storm frequency and all other parameters that make up climate.
- warming of the upper layers of the oceans leading to thermal expansion of the water. Coupled with a melting of land-based ice, this is expected to lead to a sea-level rise of between 20 and 50 cm.
- higher concentrations of carbon dioxide which, in the absence of competing effects from other sources such as acid rain and ozone, will act as a fertilizer and thus influence plant growth.



Sources of increased methane

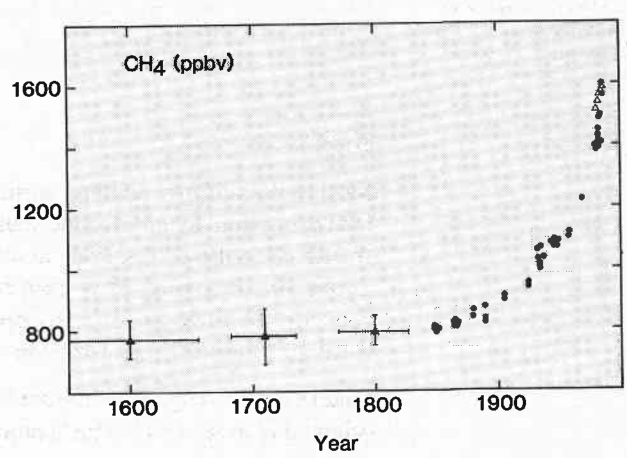
Methane, like carbon dioxide, is an important atmospheric trace gas that contributes to the greenhouse effect. If the present trends for methane and other trace gases continue, further warming will proceed at almost twice the rate expected to arise from increased carbon dioxide levels alone.

This gas also plays a significant role in controlling levels of stratospheric chlorine and hence ozone. Predictions of future stratospheric ozone levels depend strongly on the assumed growth in methane.

In the past 5 years, high-precision measurements of methane (CH_4) levels have confirmed that this gas is increasing in the atmosphere by about 0.8 % per year. Studies of air extracted from polar ice cores show that the modern increase is part of a general rise in concentration that parallels human population growth. Concentrations have increased from about 775 parts per billion (10^9) by volume (ppbv) 200 years ago, to the current level of about 1 600 ppbv.

The main sink for CH_4, accounting for 85 % of losses, is reaction with atmospheric hydroxyl (OH) radicals. The average CH_4 lifetime is about 7–11 years. The main cause of the increasing concentration is the growth of sources. The principal sources — enteric fermentation in livestock and insects, rice fields and natural wetlands, biomass burning, land fills and gas and coal fields are thought to account for 275–790 Tg/yr.

Agricultural sources are known to be increasing and both the area under rice cultivation and the cattle population have grown steadily with human population, doubling in the past 40-50 years. Part of the increase in atmospheric methane may also be due to a decrease in the hydroxyl radical sink.

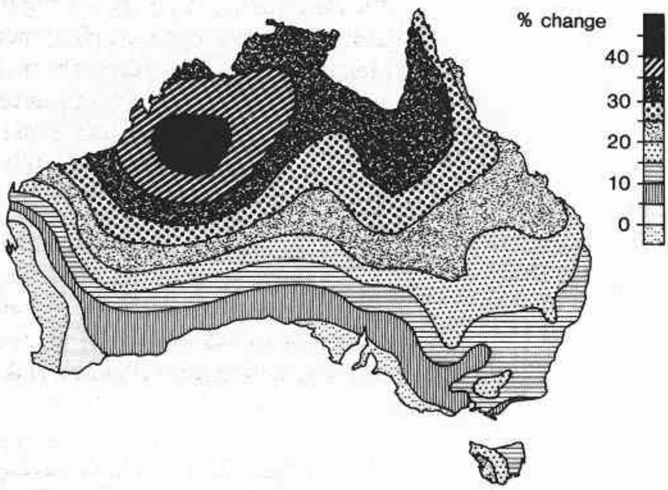


Methane concentrations determined from air trapped in Antarctic ice

Climate impacts

Scenarios for climate change on a regional scale in Australia have been developed and are being progressively refined as new information becomes available from climate modelling and paleoclimatic and other research.

An early scenario, developed during 1984, was used to assess the potential sensitivity of net primary production in Australia to a climatic change such as might be expected with an equivalent doubling of carbon dioxide in the atmosphere. In this scenario higher summer rainfall led to increases in productivity in northern Australia, while warming led to increased productivity in south-eastern Australia. Only the south-west showed any decrease in productivity. While this scenario is generally optimistic, it contains many gross simplifications and should not be taken as a firm prediction. Several factors not taken into account, such as increases in insect pests and plant diseases, could tend to reduce productivity.



Percentage change in net primary productivity relative to the present for a climate scenario roughly equivalent to a doubling of atmospheric carbon dioxide

Sulfur cycle

Most of the sulfur-containing particles that act as cloud nuclei over land come from anthropogenic sources such as coal burning and smelting of sulfide ores. Even in the most remote localities, such as over the southern oceans, each cubic centimetre of air typically contains hundreds of submicroscopic sulfur-containing particles capable of inducing the formation of water droplets.

Studies have strengthened the supposition that, apart from that originating in sea spray, most natural sulfur derives from dimethyl sulfide, produced by decomposing sea plants. Dimethyl sulfide is thought to be a significant natural source of rain-water acidity.

Although over the ocean the predominant mass of airborne particles comes from relatively large salt particles, in terms of numbers, the tiny sulfur-containing particles (Aitken nuclei) are the most abundant. The number of particles is crucial in determining the number of droplets per unit volume of cloud, and this in turn has a strong bearing on the cloud's persistence, the amount of solar radiation it reflects back to space and the likelihood of rain.

The concentrations of Aitken nuclei and cloud condensation nuclei are determined at Cape Grim. Both these classes of particles have been shown to have marked seasonal and interannual variations.

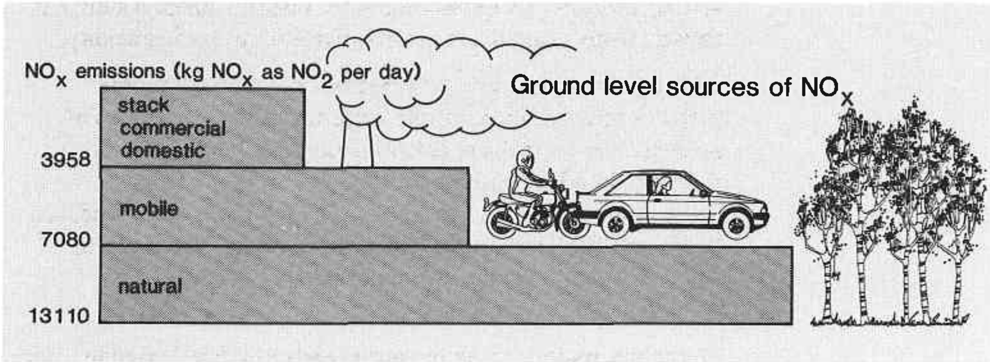
Ion chromatography has been used to find the concentration of methanesulfonate in air trapped at Cape Grim. The methanesulfonate aerosol is produced from the breakdown of dimethyl sulfide gas. A seasonal variation in concentration was found and this was attributed to changes in the biological productivity of phytoplankton according to season.

Laboratory studies have demonstrated that dimethyl sulfide produces sulfur dioxide and particles of sulfate as well as methanesulfonate. Clean maritime air always contains pptv levels of sulfur dioxide. The amount of sulfate isolated has been in excess of that derived from sea salts. This supports the suggestion that the excess sulfate originates from dimethyl sulfide.

Biogenic NO_X emissions

Evolution of nitric oxide (NO) and nitrogen dioxide (NO_2) is a small but important mechanism by which nitrogen is lost from the plant–soil system to the atmosphere. Nitrogen oxides are recognized air pollutants that have an important role in the chemistry of the atmosphere from the urban to the global scale. Nitric oxide is produced in soils during the microbial processes of nitrification and denitrification and chemically by chemo-denitrification. Nitrogen dioxide can also be produced during chemical denitrification.

These gases, once they are released into the atmosphere, combine with hydrocarbons and carbon monoxide in atmospheric photochemical processes to form ozone, hydroxyl and nitrate radicals in the atmosphere. These are the major gas phase oxidants which set in process the chemistry that removes methane, incompletely substituted halocarbons, hydrocarbons and reduced sulfur gases from the atmosphere. Thus microbial processes through nitrogen oxide emissions regulate the atmospheric concentrations of many climatically important chemical species.



About half the ground-level sources of NO_x in the Latrobe Valley are natural. In addition, major stacks liberate over 120 tonnes of NO_2 a day, but this largely escapes the boundary layer.

During this triennium there have been considerable advances in our understanding of NO_x emissions. Three field experiments have been conducted in collaboration with the Division of Plant Industry, Melbourne University and the Victorian Department of Agriculture. The fate of nitrogen fertilizer applied to flooded rice, to winter wheat and to sunflowers has been investigated along with the factors controlling these nitrogen oxide emissions. Plant cover, soil water content and soil temperature are each important in regulating the NO_x emissions.

A simple model of soil microbial and physical processes has been developed. It relates laboratory measurements on soil cores to field measurements of NO_x emissions and is the first model of NO_x emissions developed. An unanticipated spin-off of this work was the estimation of NO_x emissions from soil processes in the Latrobe Valley for the Smog Precursor Study.

Biogenic NO_x emissions in the Latrobe Valley during summer have been calculated on the basis of NO_x measurements made at various other sites with land use and environmental conditions similar to those in the Valley. Both soil temperature and either the type of vegetation or the land use were used in these calculations of NO_x fluxes.

The biogenic nitrogen oxide source from soils makes up 9% (range 4%–16%) of the total NO_x emissions into the Latrobe Valley in summer. However these biogenic emissions make up 54% of the emissions into surface air where the regional pollution problems occur. This highlights the importance of these natural NO_x emissions in regional photochemical pollution processes.

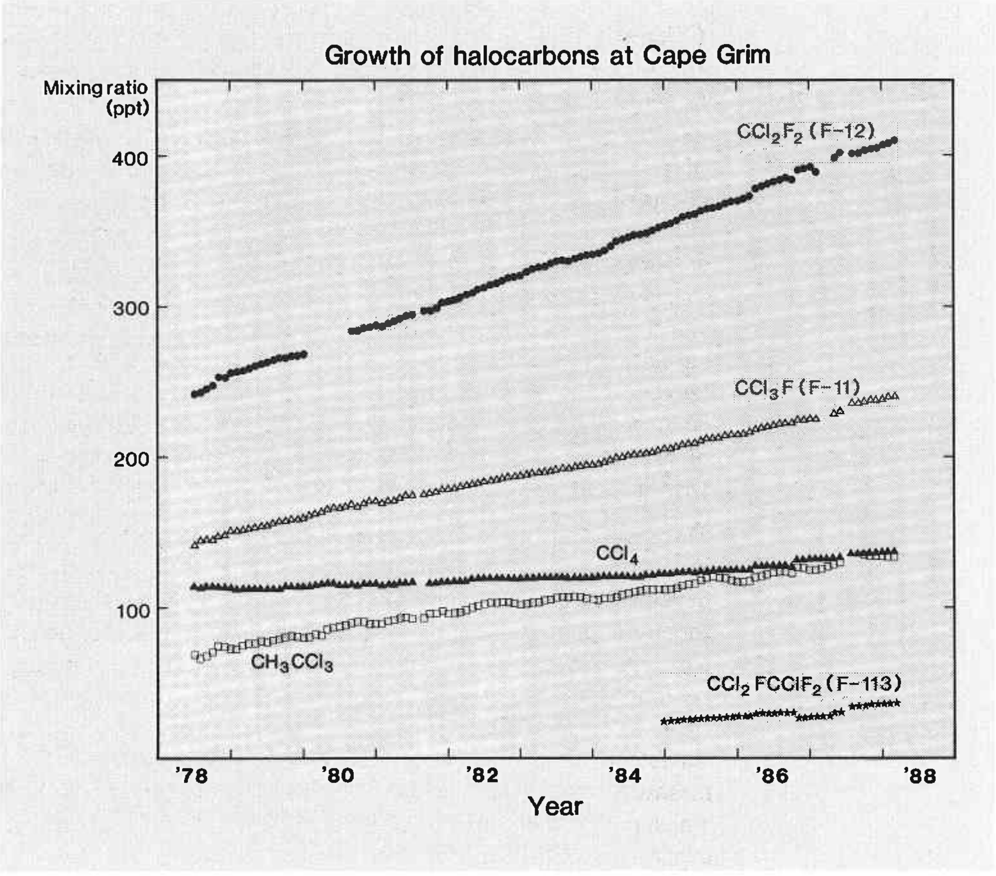
Ozone destruction

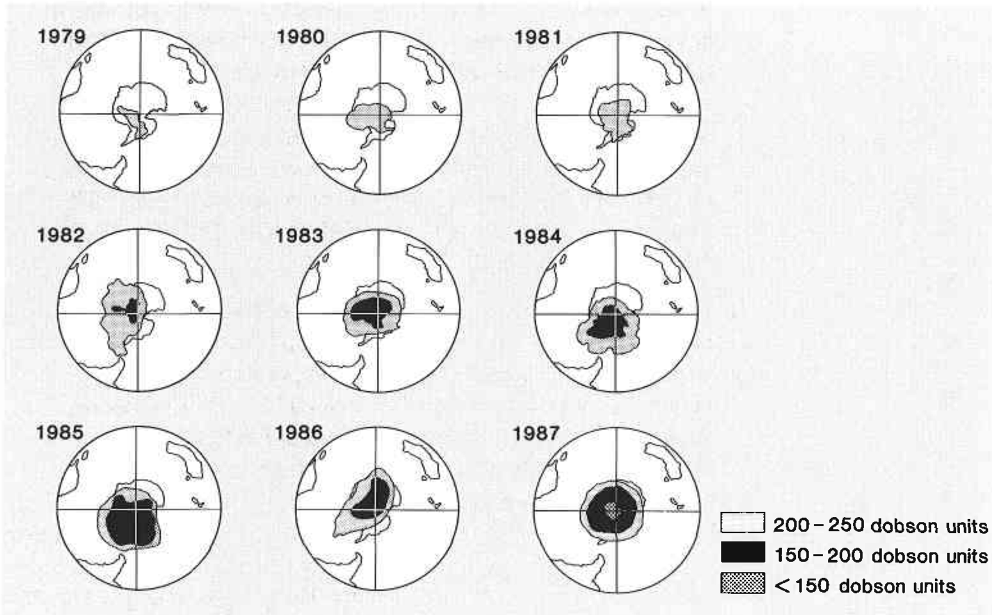
Monitoring of the ozone layer and concentrations of chlorofluorocarbons (CFCs) in the atmosphere has been done for many years. So far, a decrease in total ozone of only a few percent has been apparent, a trend that is not particularly significant in view of the large year to year variations.

At the Cape Grim Station, Division scientists are monitoring the atmospheric concentrations of the chlorofluorocarbons CCl_3F, CCl_2F_2, CCl_2FCClF_2 and $CHClF_2$ and the chlorocarbons CH_3CCl_3 and CCl_4. CFCs are used as aerosol propellants, refrigerants, foam-plastic blowing agents and solvents and the chlorocarbons as solvents, chemical intermediates and fumigants. Concentrations of these chemicals are increasing rapidly: 5% annually for CCl_3F and CCl_2F_2; 13% for CCl_2FCClF_2; 8% for $CHClF_2$; 5% for CH_3CCl_3 and 1–2% for CCl_4.

Models of stratospheric chemistry have predicted that increasing amounts of CFCs in the atmosphere result in a depletion of ozone. The problem is exacerbated by the long lifetimes of these substances. The ozone "hole" is an annually recurring decrease in ozone levels 12-20 km above the Antarctic in spring. Concentrations begin to decline in September, reach a low in October and recover again in November. A number of theories have been presented to explain the seasonal nature of the Antarctic ozone loss. All are based on the unique meteorological isolation and extreme cold of the stratosphere. Recent data strongly indicate that increasing chlorine levels, mainly from CFCs, are responsible for the Antarctic ozone hole.

The concentrations of halocarbons, measured at Cape Grim





Spring stratospheric ozone levels over Antarctica

Nuclear war

Climatic effects

Under a grant from the Australian Department of Foreign Affairs, an active research project has been undertaken to attempt to quantify the possible climatic effects in the southern hemisphere of a major nuclear war fought in the northern hemisphere. Early co-operation with scientists at the Los Alamos National Laboratory in New Mexico established an estimation of the amount of smoke from nuclear war-induced fires which might be transported at high altitudes into the southern hemisphere. For a war fought in the northern spring or summer, this was found to be sufficient to absorb some 20–30% of the incoming sunlight at heights of 10–15 km. Evidence from past studies of volcanic dust, and recent chemical studies in the U.S. suggests that this amount of smoke may be present in the southern hemisphere for up to a year or so after injection.

Three different types of climate models have been used to investigate the surface climatic effects. One is a mesoscale model, developed at Colorado State University and used at the Division for air pollution studies. The second is a coupled one-dimensional atmosphere-ocean model which was used to estimate the resulting cooling of the ocean surface. The third is the Australian Numerical Meteorological Research Centre Global Spectral Model, which is suitable for fully three-dimensional climate simulations. The mesoscale model was used for a large number of sensitivity tests which provided information about the best way to use the more expensive ANMRC model.

Results from the global model have shown that with the moderate amount of smoke likely to be overhead, serious climatic effects can be expected. Soil surface cooling due to the smoke at Australian latitudes was found to average around 3–6°C during the middle of the day and around 1–2°C at night. A large rainfall decrease occurred in the tropics and in the summer monsoon regions of both hemispheres. Similar effects occurred for both January conditions in the southern hemisphere and for July conditions in the northern hemisphere.

Reductions in crop productivity of the order of 30% are to be expected mainly due to the large reduction of rainfall. Reductions in sunlight for photosynthesis, loss of various inputs to agriculture such as fertilizers and pesticides and increases in damaging ultraviolet radiation due to ozone destruction would be expected to further reduce productivity.

Besides the profound importance of these results in relation to the potential consequences of nuclear war, the studies have for the first time used the ANMRC model for studying substantial climatic changes and give confidence in the potential application of this model to studies of the climatic impact of the greenhouse effect. Such a study is now under way.

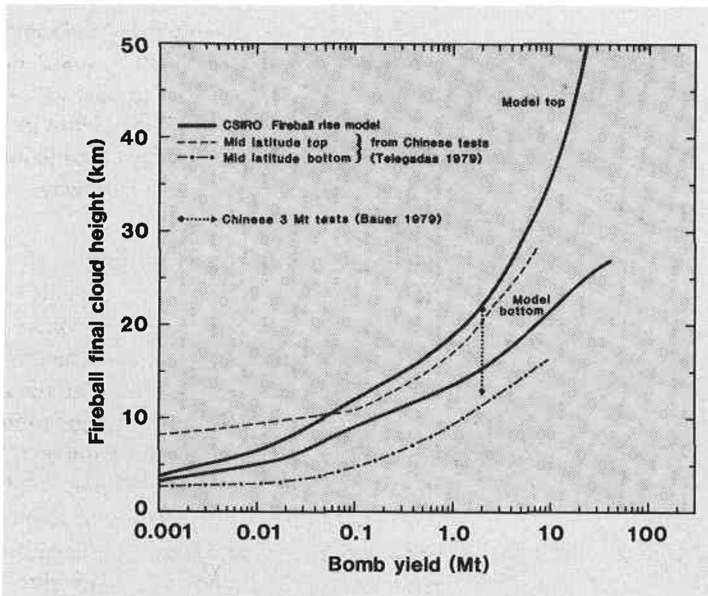
Nuclear fireball modelling

Surface nuclear explosions are capable of lofting large amounts of solid material into the upper atmosphere. American nuclear tests prior to the 1963 atmospheric test ban showed that between 30 and 300 thousand tonnes of surface material could be lofted per megaton of explosive yield. Investigations at the Division of Atmospheric Research have examined the possibility that surface nuclear explosions over fuel dumps, coal fields or regions of peaty soils might carry vast quantities of soot into the upper atmosphere, adding to the climatic effect produced by smoke plumes from mass fires. This mechanism, if effective, would be of particular importance to the southern hemisphere because the normal loss and delay mechanisms operating on smoke plumes would not occur. This would lead to greatly increased soot amounts in the upper atmosphere, with enhanced detrimental climatic effects in our latitudes.

A numerical model of the ascending stage of a nuclear fireball has been developed and simulations compare favourably with available data from mid-latitude explosions.

A chemical scheme for the uptake of carbon and combustion of soot particles in the fireball has been developed and incorporated into the model. Both standard runs with the model and sensitivity studies for a range of conditions indicate that all the soot particles within the fireball burn up as the hot fireball ascends in the air and no soot is released into the upper atmosphere. It thus appears that this mechanism will not contribute extra soot to the upper atmosphere after a nuclear war. Estimates of the climatic effects should therefore be based on soot production from fires, carried into the upper atmosphere by smoke plumes, and to a lesser extent on non-sooty dust particles carried aloft by the fireballs.

Further work has been carried out with the fireball model to examine the rate of injection of nitrogen oxides into the upper atmosphere from the fireballs. Preliminary findings indicate that the rate calculated from this model is substantially less than that estimated by previous workers. Thus depletion of ozone in the upper atmosphere due to nitrogen oxides from the nuclear explosions may be less than originally thought. It should be noted however, that there are other processes involved in the potential destruction of ozone following a nuclear war.



The influence of bomb yield on the final cloud height of a fireball

Teleconnection patterns

Large-scale dynamical processes of the extra-tropical troposphere are usually considered as processes in which the fluctuations have scales greater than about 250 km and periods larger than about one day. Within this range, there exists a wide variety of disturbances including relatively small-scale extra-tropical cyclones or lows, anticyclones or highs, blocking dipoles consisting of high-low pairs aligned in the north-south direction and very large-scale teleconnection patterns which may be of hemispheric or even global extent. Teleconnection refers to the fact that the climate in one part of the world may be related to the climate in a distant region through these large-scale features of the circulation.

Teleconnection patterns have profound effects on the weather and climate, producing severe storms in some regions and droughts in others. A theory of the formation of anomalous circulations due to atmospheric teleconnection patterns has been developed and compared with observations for the northern and southern hemispheres. For some teleconnection patterns such as the western Atlantic northern hemisphere pattern, topography plays a very important role. For others, such as the Pacific North American pattern it plays only an indirect role in the growing stages of the pattern. Detailed studies have been carried out using a variety of theories and numerical models to elucidate the role of topography in the formation of teleconnection patterns. The modelling of climate is further discussed in the Water Resources section of this report.

Atmospheric Pollution

Introduction

This program studies the atmosphere and surface and source characteristics which influence air pollution and bushfires. It is developing improved methods of predicting the local and regional impact of pollutant source emissions and the outbreak and spread of bushfires for both planning and regulatory purposes as well as for disaster management.

Theoretical analysis, numerical model experiments, laboratory experiments and field measurements are used in the investigations. The focus is on identifying sources of pollution and the way in which it is transported and dispersed by local and regional winds in the boundary layer. Chemical transformation among pollutant species and the interaction between local winds, bushfire dynamics and topography are being studied.

An efficient three-dimensional mesoscale model has recently been developed. The model has now been successfully tested in a nested mode for several problems of flow over complex terrain.

Latrobe Valley Airshed Study

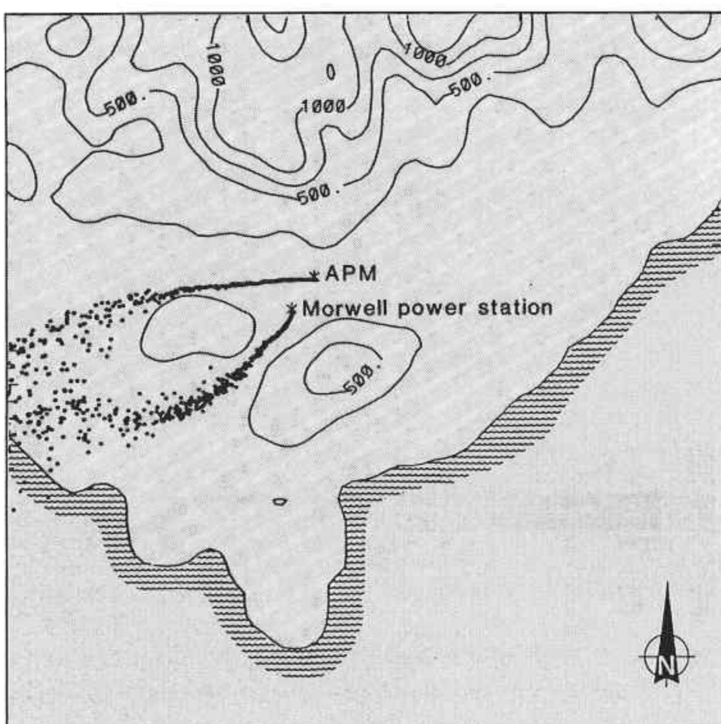
After 11 years of operation the Latrobe Valley Airshed Study has been completed. The study was carried out in collaboration with personnel from the Applied Meteorology and Tropospheric Chemistry Groups and several other organisations. It has led to advances in the modelling of visibility reduction due to fine particles, photochemical ozone formation and long-range transport of emissions from Melbourne. The models included Lagrangian photochemical–trajectory, multi-level box, Gaussian plume, puff diffusion and grid-point prognostic types. In collaboration with the Chisholm Institute of Technology, diagnostic wind field modelling — the basis of the Lagrangian and puff models — was advanced to include effects of stable ambient temperature fields. A number of Latrobe Valley field studies have been undertaken.

Plume tracking studies

The final two Experiments were successfully undertaken in winter 1985 and summer 1986 in collaboration with the State Electricity Commission of Victoria (SECV). A massive set of upper air and surface meteorological and air quality monitoring data has been assembled. The Experiments, funded by the National Energy Research, Development and Demonstration Council (NERDDC), have been extremely important for model development by participants in the Airshed Study. The CSIRO research aircraft was used to track the paths of power station plumes over distances of 100 km to the east and west. Additional upper air data were collected by balloon sounding and extensive surface observations were made.

A three-dimensional mesoscale model has been used to further understanding of flows observed during this study. Using a 5 km grid length over a 250 x 250 km domain, the model is successful in predicting the flows which dominate the region in the warmer months, in particular the sea breezes from the east and south coasts which meet near Morwell in the late afternoon. Anomalous westerly winds in the morning hours, under a weak northeasterly synoptic pressure gradient, were found to result from an inertial oscillation of the remnants of the previous day's sea breeze and slope wind circulations. The use of radiative conditions at lateral boundaries was necessary for realistic results in the complex terrain and enabled simulations to run for 48 hours.

Understanding and prediction of such complex wind fields is important from the standpoint of pollutant dispersal in the Valley. A Lagrangian particle dispersion model, driven by wind and turbulence statistics from the mesoscale model, has been used to investigate this problem. With the current distribution of emitters, the sea breeze advects clean maritime air up the Valley to Yallourn and beyond, but the addition of sources towards the



Simulation of plume dispersion in the Latrobe Valley. Particles were released from sources at Morwell power station and Australian Paper Mills. The lower stack height at APM results in a different direction of particle transport from that of particles from the higher Morwell stack.

coastline would cause pollutant concentrations to rise as the sea breeze moves inland. In stable night-time conditions when there is little mixing of plumes to ground level, strong vertical wind shear from terrain effects can lead to markedly different trajectories for plumes from sources with differing effective stack heights.

Latrobe Valley smog precursor study

It is only possible to understand and accurately model photochemical ozone production with, amongst other information, a knowledge of the sources and concentrations of reactive hydrocarbons and nitrogen oxides within the air. Thus development of any scenarios for ozone exceedences in the Latrobe Valley is dependent on reliable information on these.

Unfortunately at the time of this study, unlike other air pollution measurements, for example ozone and local visual distance (LVD), no adequate method existed for routine measurement of reactive hydrocarbons in the regional atmosphere. Early attempts to measure non-methanic hydrocarbons in the Latrobe Valley were hampered by insurmountable technical difficulties associated with equipment. These measurements led to the erroneous conclusion that there was around 400 ppbC (ppb = 10^{-9}) of non-methanic hydrocarbons (NMHC) in rural air in the Valley, a value perhaps twenty times higher than is now accepted. The first accurate information on NMHC levels in rural air in the Latrobe Valley was obtained when reactive hydrocarbons (C_2 to C_{10}) were measured at the Minniedale Rd Air Quality Monitoring Station during autumn 1986 and summer–autumn 1987 using an automatic speciating gas chromatograph developed at the Division.

The mobile laboratory housing the automatic speciating gas chromatograph on site in the Latrobe Valley.

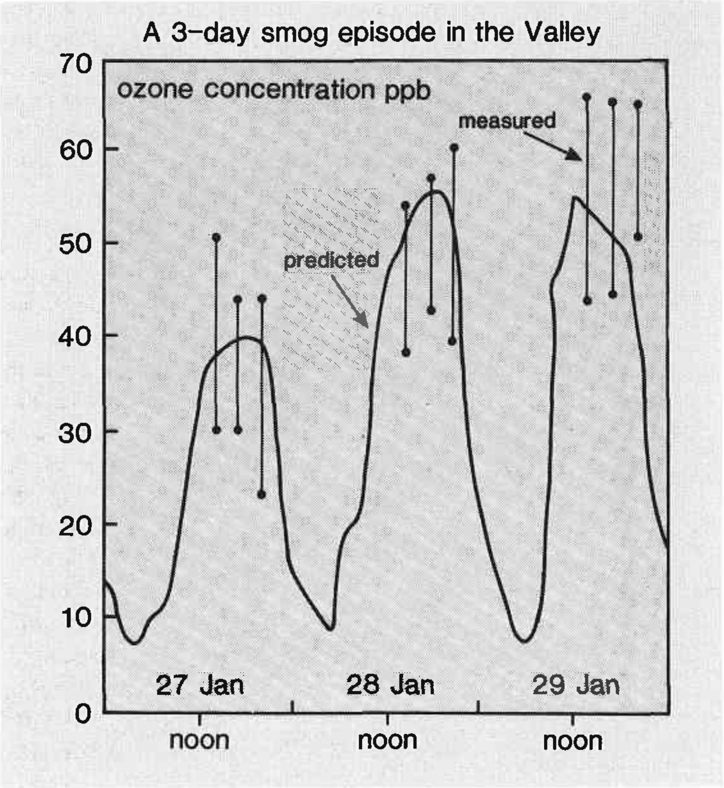
Subsequently in the summer of 1988, grab sampling of NMHCs was conducted at ground sites and from an aircraft in the Latrobe Valley. Samples were also taken in a forest area and from the Yallourn open cut coal field to make a preliminary assessment of potential special sources of hydrocarbons. The data obtained gave the first clear picture of the spatial distribution and variability of NMHCs in the Valley.

On photochemical smog prone days, the measurements showed around 20 to 30 ppbC of C_2 to C_{10} hydrocarbons with little systematic variation both with height and around the Valley. The mix of hydrocarbons observed, when compared with emission mixes for Sydney and the eastern suburbs of Melbourne, appeared to be already aged by photochemical processes. These aircraft and day-time measurements were in some cases upwind of the hydrocarbon sources. These observations have been interpreted as being due to the presence of a background NMHC level in air over south-eastern Australia before it entered the Valley. This background level was probably due to the long traverse of the air over land in the northerly air flow that coincided with smog prone conditions during these summer-autumn months. Anthropogenic hydrocarbons emissions are related to population density. Consequently, hydrocarbon emissions per unit area do not vary significantly from those in the Valley for other rural areas of Victoria and southern New South Wales. Air would have been exposed to these rural hydrocarbon emissions for several days before it entered the Valley.

In forested regions of the Valley natural reactive hydrocarbons from vegetation, including isoprene and 1,8 Cineole (eucalyptus oil) contributed one third to one half of the C_2 to C_{10} atmospheric hydrocarbon concentration. These observations provide evidence that, as well as local emissions, regional transport and natural emissions contribute to photochemical ozone production in the Latrobe Valley. With this precursor information available as well as the natural NO_x emission inventory, a collaborative effort on computer modelling of photochemical smog in the Latrobe Valley was set up between the EPAV and CSIRO.

The model took into account 40 chemical species reacting through 83 pathways. Conditions existing during a 3-day smog episode during 1988 were fed into the model. The Valley is prone to such long-lived episodes because of its "boxed in" nature. During this episode, when the Valley was shut off from outside sources, the observed 1-hour maximum ozone levels at rural sites not influenced by power station emissions were 36 ppb, 44 ppb, and 50 ppb on the three days.

On 29 January the maximum measured ozone concentration in the Valley was 59 ppb, but the recording station in question is thought to have been influenced by power station emissions.



Assuming comparable quantities of natural and artificial precursors (NO_x and reactive organic carbons), modelling of trapped emissions gave predicted levels close to observed ones.

Modelling reflected the actual observed ozone levels fairly accurately as the graph indicates. Moreover, it showed that the ozone levels were NO_x-limited — that is, the amount of ozone produced was restricted by the availability of NO_x rather than by that of hydrocarbons. In this situation where half the surface-emitted NO_x came from natural sources, ozone levels would be approximately reduced by one-third if these natural sources were absent. On the other hand, modelling showed that halving (or doubling) the hydrocarbon figure would have very little effect on the ozone levels reached.

Aerosol/Visibility study

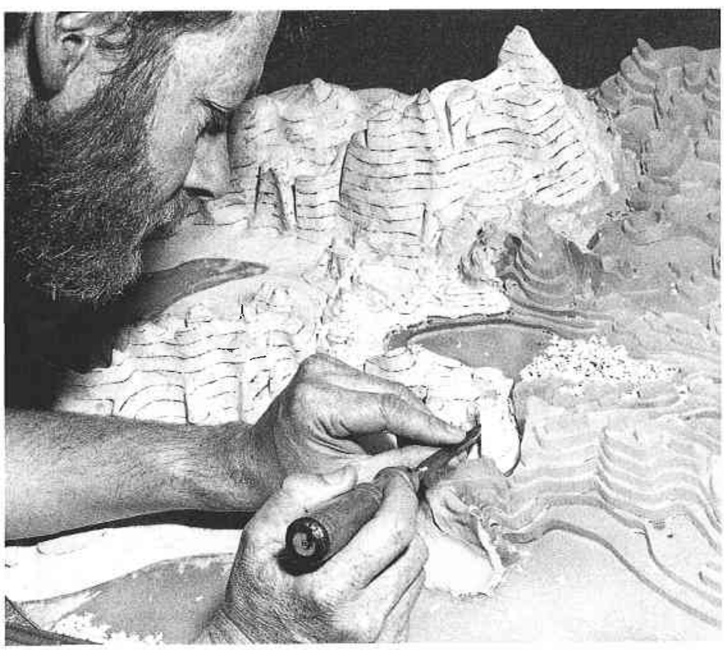
This project aimed at determining the sources of aerosol on days when visibility in the Latrobe Valley falls below the designated accepted level. The Study was funded jointly by DAR, NERDDC and the SECV. Properties of sub-micrometre aerosol particles were determined either by *in-situ* sampling or by subsequent laboratory analysis of samples taken at three sites in the Valley.

Physical and chemical properties peculiar to individual sources of aerosol in the Valley were used to determine the role played by these sources in determining atmospheric visibility. Aerosol types readily identified include sea salt, soil dust, photochemical (smog) products, power station emissions and effluent from biomass burning. An unexpectedly large proportion of aerosol on occasions of low visibility appears to be composed of organic hydrocarbon material. At this stage the major source of this aerosol cannot be quantitatively identified. However, there is considerable circumstantial evidence suggesting that it is bush and grass fires.

Air-flow in the Sofia Vale

Vertical stability in the atmosphere is an important controlling factor for many types of meteorological phenomena. It is of particular importance in confined regions such as the Latrobe Valley in Victoria and the Vale of Sofia in Bulgaria. As part of an international exchange scheme the Division has undertaken a study of the Vale in collaboration with the Bulgarian Academy of Science.

The value of such a collaborative program to Australia is that it enables the theory and the laboratory modelling techniques developed at the Division to be tested in an area of extremely complex terrain with the validatory field work being carried out by the Bulgarians.



Construction of a model of the Sofia Vale in Bulgaria

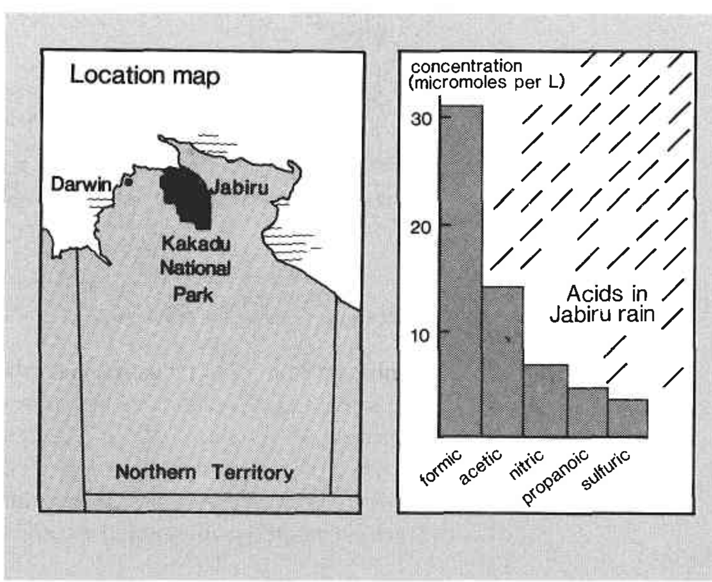
Significant sources of industrial and urban atmospheric pollution are present in the Vale, and on occasions of synoptic blocking air stagnates below the crest-line of adjacent mountains. Frequently occurring conditions of light winds, cloudless skies, stable stratification and strong surface heat flux cause the diurnal development of a well-structured convective boundary layer. The height of this layer plays an important role in determining the ability of the atmosphere to disperse pollution. The diurnal development is controlled by the amount of sensible heat liberated at the earth's surface and therefore it is important to identify the factors influencing the surface heat flux. Routine meteorological observations have been used to estimate this heat flux and its diurnal development at different times of year. This has enabled determination of convective boundary layer heights.

As part of the study, a 1 cm : 200 m horizontal scale model of the Vale was constructed and then towed through a laboratory water tank. This technique has important relevance both to scientific understanding of flow patterns over complex terrain and to practical problems of locating atmospheric pollution and identifying its sources. The experiment has enabled tentative hypotheses to be made regarding wind direction and pollution levels in the Vale. The information should be of assistance in planning validatory field studies during periods of stable conditions and light prevailing winds.

Acid rain in the Northern Territory

It has been known for some time that there is a widespread occurrence of acidic rainwater in the Northern Territory. Water from individual storms has given pH readings as low as 3.5. Scientists from the Division have studied the source of this acidity in collaboration with the Northern Territory Office of the Supervising Scientist.

A high-performance liquid chromatograph was used to identify and measure the types of acid present in rainwater samples



The average pH of rain-water collected at Jabiru was 4.3. Most of the acidity comes from formic acid.

collected at Jabiru. Results showed that formic acid and acetic acid contribute most to acidity. The level of sulfuric acid, which is the major contributor to acid rain in industrial regions, was consistently low.

Plants are thought to be the source of the acids present in the rainwater. Isoprene makes up more than one third of complex hydrocarbons released by plants. This compound is particularly volatile and reactive at the high temperatures found in tropical regions and it is suggested that under the action of sunlight it forms organic acids. Bush and grass fires may also contribute appreciable amounts of compounds that turn into organic acids.

In order to investigate the isoprene more thoroughly, a series of air samples were taken on the ground and from the CSIRO research aircraft. At ground level, isoprene concentrations of from one to several parts per billion by volume were detected. Concentrations decreased with altitude and were consistently lower at high altitude. Carbon monoxide is one of the break-down products of isoprene. Greater than normal concentrations of this gas were found at all altitudes.

Analysis of cloud-water droplets gave an average pH of less than that of the rain samples collected on the ground. The difference may be due to dilution of the acid as the water droplets in clouds grow to raindrop size. About 60% of the total acidity in both cloud droplets and rainwater is due to formic acid and 20% to acetic acid. Other organic acids were present and both nitrate and sulfate contribute to the acidity.

Ground-level measurements of aerosol and gas compositions fitted in with these findings. Scientists have concluded that most of the chemicals found in air in the Northern Territory come from natural sources. Sulfate is the only man-made source of rain-water acidity in tropical Australia.

Turbulent dispersion

Within the wider context of providing a unified statistical treatment of turbulent dispersion for arbitrary flow fields and arbitrary source distributions, research has focused on two areas.

The first of these concerns fluctuations in concentration about the mean value due to the inherent stochastic nature of turbulence and turbulent dispersion. Such fluctuations are important because they are generally at least as large as the mean value and therefore represent an inherent limit on the certainty of both measurements and model predictions of the mean. They also enter into the physics of the analysis of phenomena such as chemical reactions (including fire and explosions) in turbulent flow and influence the response of biological and mechanical entities to pollutants.

The second concerns dispersion in the convective boundary layer, which under Australian conditions often accounts for the highest ground-level pollution levels from large elevated point sources such as power stations and smelters. Due to the large, energetic eddies which dominate turbulence under these conditions, the usual two-stage approach to plume dispersion — a near-field buoyancy-dominated stage and a far-field stage dominated by atmospheric turbulence — is less appropriate. A more unified approach is called for in which the statistical properties of the spatial and temporal distribution of pollutants are studied, described and modelled in terms of the joint effects of plume buoyancy and atmospheric turbulence.

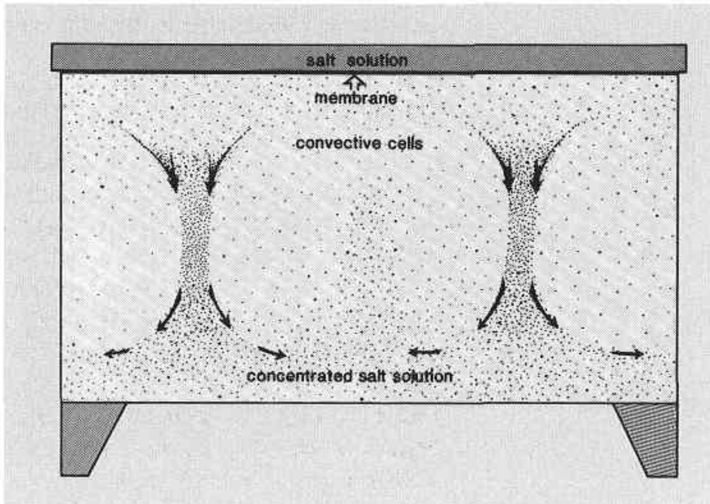
These problems are being examined through an interactive combination of theoretical, laboratory and field studies.

The theoretical work has progressed on two fronts. Firstly, fundamental studies of fluid accelerations provide both parameter inputs and justification for developing a Lagrangian mathematical model of turbulent dispersion. A number of new basic results have been found. Secondly, the working model of dispersion has been used in a number of complex flows to predict mean pollutant concentrations. However, the concentration fluctuations, which are output from newer more complex Lagrangian models, are not yet well understood. The mean-concentration models have been validated against wind-tunnel data, laboratory data and field experiments, all of which are part of the overall program. The concentration-fluctuation models had not previously been well enough defined to warrant comparisons with experiment. However, the fundamental work has greatly aided formulation and the comparison (with wind-tunnel data) is now feasible and will lead to working models for concentration fluctuations.

Laboratory experiments provide a bridge between theory and field observations. Dispersion experiments in a wind tunnel provide basic data on concentration fluctuations which are used to test and validate theory.

Laboratory measurements of dispersion in a convective boundary layer will be undertaken in a new convection tank that is being built as part of a 3 year research fellowship funded by the State Electricity Commission of Victoria (SECV). A novel feature of the 3.2 m x 1.6 m x 0.8 m deep glass-walled convection tank is the use of saline solutions to generate the buoyancy flux normally produced by heat. This widens the range of conditions that can be modelled and simplifies the operation of the apparatus.

The model will initially be used to study the interaction between the turbulence structure of the convective boundary layer and that generated by the rising buoyant plume with a view to obtaining a full parametric description of buoyant plume dispersion. Further work will be directed towards measurements of concentration fluctuations. These results will aid the development of improved dispersion models by providing much more complete sets of data than are possible in the ever-changing atmosphere. Laboratory modelling of the atmosphere is further referred to in the Water Resources Section of this report.



Saline solutions, added through a porous membrane at the top of the tank are used to generate the buoyancy flux normally produced by heat. Convective cells can be set up in this process and the tank mimics the atmospheric boundary layer upside down.

Finally, preparations have been in progress for a major field study of the dispersion of a large buoyant point source under convective conditions. This experiment at Tarong power station in Queensland is funded by NERDDC and is a collaborative venture which aims to provide a set of dispersion data. It is hoped that this set of data, through scaling by appropriate meteorological and emission parameters, will be applicable to other locations and will provide a test bed for laboratory and theoretical studies.

Cold fronts modelling

The interaction of summertime cold fronts with a diurnally heated land mass has been studied using two-and three-dimensional models. This study has advanced understanding of frontal movement to the stage where convective heating of the boundary layer over land is now known to change dramatically the basic structure of a front and hence its mode of propagation. During the Cold Fronts Research Program, two categories of fronts differing in basic low level structure were observed and it now appears that the presence or lack of boundary layer heating is largely responsible for these differences.

Insight has also been gained into the means by which fronts approaching the coast in afternoon and early evening hours appear to accelerate greatly along the southwest Victorian coastline. In prefrontal situations, a day-time pressure trough develops at the coastline or just inland if there is a sea breeze. This is due to the diurnal pressure fall over land. Experiments show that the typical frontal characteristics — wind shift, temperature fall and pressure rise — of an approaching front may be transferred at some stage to the coastline trough, which then becomes the main front. The organisation of an offshore frontal system in such a way is also responsible for the large percentage of summertime fronts which pass through Melbourne in the afternoon and early evening hours.

Flow over complex terrain

The formation mechanisms of the Melbourne eddy have been clarified in a series of numerical simulations, performed jointly with the Meteorological Research Institute of Japan (MRI). The MRI mesoscale model was used with a 10 km outer mesh and a 5 km inner mesh. Two different cyclonic eddies with separate formation mechanisms were identified. The first is generated by vorticity shed from the upstream Australian Alps, and corresponds to earlier laboratory simulations. Day-time anabatic effects were found to enhance the strength of the eddy. The second type of eddy is generated by interaction of the sea-breeze front with a weak synoptic northwesterly flow.

The MRI model was also used to study flow over the complex terrain of the Latrobe Valley, with particular attention given to sea-breeze behaviour. For negligible prescribed background synoptic flow, there was little difference between 5 km resolution nested and non-nested predictions. The arrival times of the sea-breezes in the Latrobe Valley were found to be in good agreement with observations. With a moderate north easterly synoptic flow the nested simulation revealed upstream orographic effects. In particular a weak nocturnal eddy formed over the Latrobe Valley, and the east coast sea-breeze was retarded in agreement with observations. The eddy formation probably depends on both wake and diurnal heating effects.

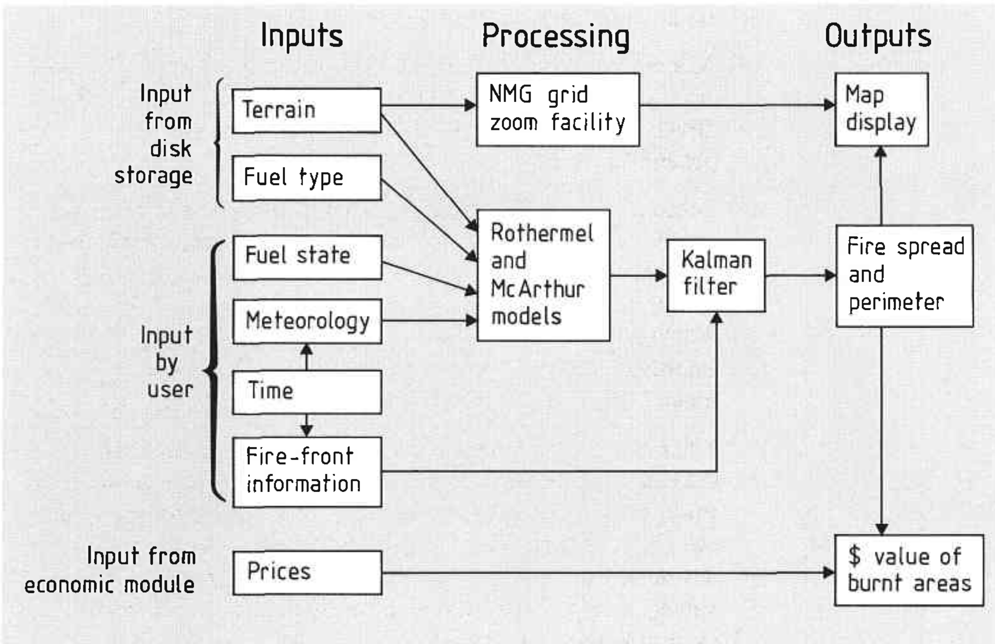
Bushfire meteorology

A National Bushfire Model which features the use of computer colour graphics is being developed. Dynamic optimisation is incorporated so that model parameters can be altered when field data indicate discrepancies between model predictions and real-time wind or fire-front observations. It is scale-free so it is able to handle a small fire in a single paddock as well as a major conflagration such as Ash Wednesday.

The National Bushfire Research Unit conducted field experiments on Northern Territory grasslands during August 1986. Statistical analysis of the results indicated that existing bushfire models performed poorly. It suggests, however, that the Kalman filter would perform well as an optimising tool. The Kalman filter is a statistical technique designed to optimise the output of a system by comparing the discrepancy between observations and predictions and then altering the predictions in order to minimise the error. This has been incorporated into the proposed design of the National Bushfire Model.

Analysis of past meteorological data reveals that years of extreme bushfire danger are characterized by low atmospheric humidity. To predict bushfire danger under future climatic scenarios therefore requires detailed knowledge of the future atmospheric moisture, in particular, relative humidity. This is the atmospheric variable most critical in determining long-term bushfire danger.

A flow diagram showing the modules comprising the National Bushfire Model.



Remote Sensing

Introduction

The flows of solar and thermal terrestrial radiation through the atmosphere and their interactions with the atmosphere and land and ocean surfaces are what, in the first instance, determine the climate in which we live. Studying these processes is therefore vital to our understanding of climate and climate change, particularly at the earth's surface.

Modern research in this area involves remote sensing techniques from satellites, aircraft and the surface. Recent emphasis at the Division has been on meteorological satellites as well as ground-based laser ranging (lidar).

Sensors on satellites normally operate at wavelengths from the visible to the microwave and collect information about the earth's atmosphere, oceans, land and ice surfaces. These satellites monitor the planet at a variety of altitudes from low polar (approximately 200 km) to high equatorial (approximately 36 000 km). The information is commonly processed into the form of a photographic image or collected as an array of digital data.

The Division of Atmospheric Research is also involved with developing, and where appropriate, commercializing technology for investigating climate and the natural environment. Activities have included the design of new space-borne instruments, development of lidars as well as the demonstration of new value-added products and design of image processing from existing operational satellites.

The development of CSIDA (the CSIRO System for Interactive Data Analysis) has continued. It is now a complete system for receiving and processing meteorological satellite data and itself has commercial potential. A detailed description of CSIDA appears in the Division's previous research report.

Lidar applications

Instrumentation

The Divisional ruby lidar has been upgraded with improvements to the optical system, electronics and alignment systems. The data acquisition system has been completely redesigned and now works from a PC system. New depolarization equipment has been added to the ruby lidar for more accurate profiles. A commercial lidar for cloud base and other measurements is being developed and partially funded by the Tasmanian Development Authority. The design, simulations and the software package were supplied by the Division with additional funding being supplied by Sirotech and the Cape Grim Baseline Station. The prototype instrument will be used for scientific investigations at Cape Grim in Tasmania.

The narrow-beam infrared filter radiometers developed at the Division have been updated and continue to be used. The Division's infrared tuneable lidar has also been improved. Commercial collaborative opportunities are being sought to further develop this instrument.

Lidar.

Lidar provides a technique for measuring the properties of the atmosphere at ranges of up to 30 km. In the study of atmospheric pollution, it may be used to track emission and dispersion of plumes from industrial sites, and to measure concentrations of a number of pollutants including sulfur dioxide, nitrogen dioxide, ozone and various organic molecules.

Lidar may be operated from the ground as well as from aeroplanes and satellites.

Development of more sophisticated lidars allows measurement of humidity, wind velocity and turbulence. It also permits detection and measurement of molecules which occur in very low concentrations. The concentration of stratospheric ozone may be determined using lidar.

The lidar instrument employs a laser to send pulses of light into the atmosphere. Aerosols and cloud particles reflect the light back into an optical telescope connected to a processing system which allows the data to be analysed.

Cloud radiation studies

Clouds are made up of water droplets and ice crystals. The scattering and absorption of atmospheric radiation can at times be very strong. Many clouds transmit less than 50% of solar radiation. Without the presence of clouds in the atmosphere, the mean surface temperature of the earth would be 15°C warmer. While ground based lidar has been the main tool for studying clouds, aircraft and satellite measurements have also been used.

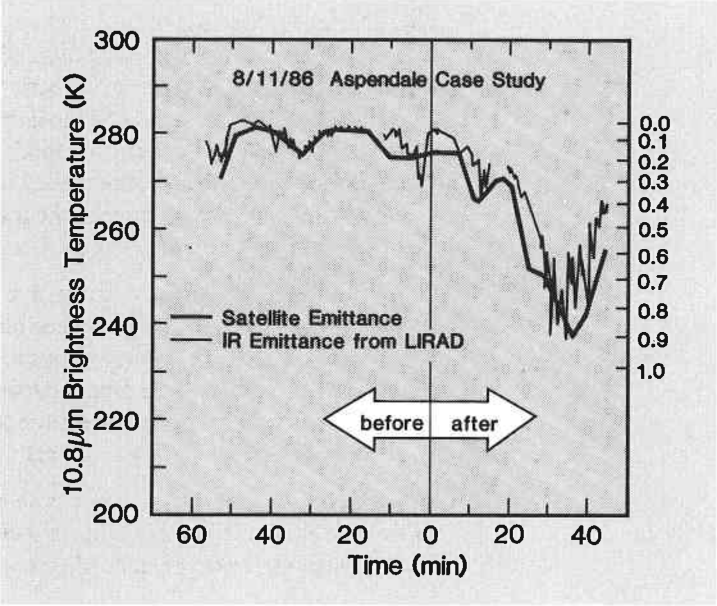
Long term research is being conducted to obtain a better understanding of the relations between cloud extinction, liquid water content and particle mode radius in layer clouds. Such an understanding is basic to the proper parameterization of cloud optical properties in climate models and to the climate feedback properties of these clouds in any global warming.

Progress has been made on the vital role of particle size and its variation with temperature in cirrus clouds. An important discovery has been the presence of layers of cirrus containing much smaller particles than considered possible. These layers will radiatively tend to have a cooling effect on the atmosphere. Sizing and counting of particles from many replica tapes taken in situ in cirrus in US missions and analysed at the Division shows, for the first time, the presence of many small columns, bullets and needle crystals. Analysis and interpretation of NASA data obtained by a lidar and scanning radiometer overflying cirrus, together with in situ cloud physics microphysical data, revealed the presence of layers of small crystals (5-10 µm radius).

Analysis of cloud microphysical data has revealed the general dominance of cloud particle size in determining the cloud optical properties. A deep precipitating system with 50 times the liquid water content has a similar volume extinction coefficient to boundary layer stratocumulus due of the presence of large precipitating particles in the former clouds. A parameterization of cirrus cloud in terms of solar albedo, infrared emittance and the global temperature change has been devised based on previous lidar/radiometer (LIRAD) observations of cirrus clouds taken at Aspendale.

A study has also been done using satellite data and LIRAD ground -based data at Aspendale. The 3.7 µm and 11 µm wave-length radiances from cirrus were compared with simultaneous ground-based lidar measurements of the optical depth. It was found that the difference between the two channel radiances was related to the ground-based optical depth in a manner which agreed reasonably well with theoretical models.

Most of the above studies have been undertaken in collaboration with various U.S. colleagues, emphasising the international nature of this climate work.



Emittance of a cirrus cloud from satellite and ground based (LIRAD) determinations. The satellite passed overhead 60 minutes after the commencement of measurements.

Support studies for a satellite wind lidar

Division scientists were involved in collaborative work with NASA in 1986 to study the microphysical and backscatter properties of the southern hemisphere aerosol using ground-based lidar and aerosol sensors. The backscatter profiles, taken in various locations between 4°S and 41°S, agreed quite well with calculations from aerosol size distributions measured on the CSIRO F-27 research aircraft by colleagues in the Global Atmospheric Change Program. The NASA Continuous Wave (CW) CO_2 coherent lidar, on board the aircraft gave low backscatter values at 10.6 μm, in agreement with the aerosol data. The low southern hemisphere values have important implications for the design of a satellite doppler lidar.

The Division is involved with simulating cloud back-scatter for the NASA Lidar-In-Space Technology Experiment to be conducted in 1993. Simulations of backscatter from clouds for a satellite lidar have indicated that multiple scattering will result in a significant improvement to the transmission of lidar pulses through clouds.

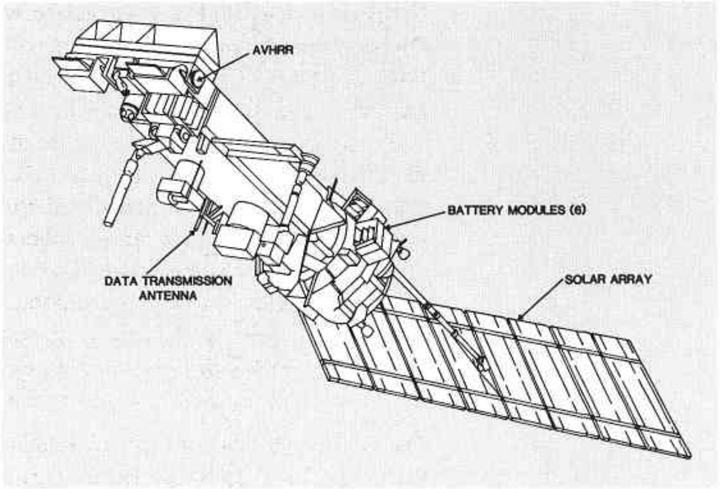
Satellite applications

Introduction

Accurate numerical modelling of the world's weather and climate and our understanding of their physical processes are dependent on the availability of high quality data describing the earth-atmosphere-ocean system. Operational satellites provide the only means by which sufficient global data can be provided at the frequency required. Studies are aimed at the useful interpretation of data obtained from meteorological satellites. Data from the Division's satellite reception system are being used in a number of research projects involving the interaction of solar and thermal radiation with the atmosphere, land and ocean. These efforts are an important part of the Division's climate change program. One of the major thrusts is to provide a satellite data base for the investigation and detection of regional climate change within Australia.

The work involves active participation in important international programs including NASA's Earth Observation System (EOS), the ISCCP (International Satellite Cloud Climatology Program), ECLIPS (Experimental Cloud-based Lidar Pilot Study) and the ERS-1 program of ESA (European Space Agency). There are also important interactions with primary industry.

The scientific effort is also balanced by a "space hardware" program in which support is given to Australian industry involved in the building of appropriate instrumentation. Space hardware for the ERS-1 satellite has been built in Adelaide, a prototype for a



The Advanced TIROS satellite

new satellite instrument is under development in Canberra and further transfer of space technology to Australian industry is under way.

Vegetation properties

The index of vegetation greenness, NDVI (normalised difference vegetation index) is being used to study grassland fire potential in rural areas of Victoria in collaboration with the Victorian Country Fire Authority. The NDVI is subject to errors caused by radiation scattering in the atmosphere and effort has been put into devising corrections for these errors. A fast radiative transfer scheme for rapid calculation of corrections has been developed and is now in use.

Flood monitoring

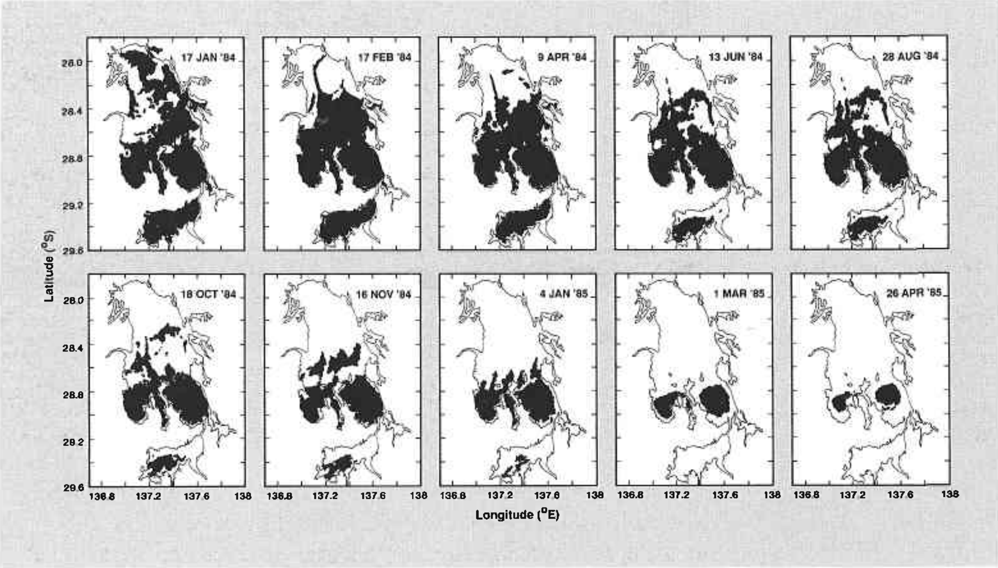
The potential use of meteorological satellite data in the monitoring of flood waters in inland Australia is under investigation. The extensive rainfall over the central Australian regions in the last three years has provided a useful data set for this study. Preliminary work shows that the operational meteorological satellites can give details on the movement of flood waters as well as the extent of the flooding.

Antarctic satellite remote sensing

In conjunction with the Glaciology Section of the Antarctic Division, NOAA AVHRR imagery is being used to detect open water polynyas (areas of open water surrounded by sea ice), thin ice types and ice thickness within the Antarctic sea-ice zone. The extent and thickness of sea-ice forms an important control on the oceanic heat loss and surface albedo which in turn influences the global climate. Two studies have shown that, within the Antarctic sea-ice zone, the concentration of open water and thin sea-ice are the dominant factors affecting the exchange of heat from ocean to atmosphere thus influencing cyclogenesis and cyclolysis. Algorithms under development are to be used for identifying regions of potential high latitude synoptic development.

Other applications

New applications of AVHRR (Advanced Very High Resolution Radiometer) satellite data have been developed. These include a method for detecting hazardous volcanic eruption clouds and a simple scheme for determining evaporation from arid zone lakes. Joint work with the Division of Oceanography has continued on studies of the Leeuwin current, a warm, poleward current flowing off the western Australian coast.



Computer-enhanced satellite images showing the evaporating waters of Lake Eyre

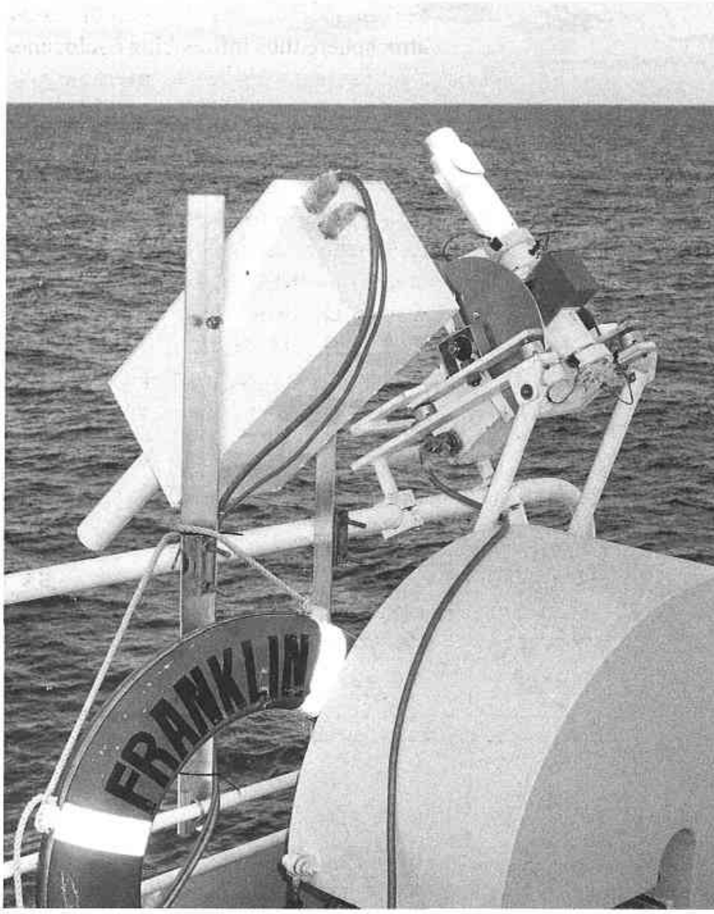
Satellite atlas

Over the next three years all the useful meteorological satellite data will be combined into a satellite atlas of Australia. This will include products such as seasonal values of NDVI, land and sea surface temperature, evaporation and clouds. The atlas aims to demonstrate how satellite data can be applied to various community and industrial problems.

Satellite instrumentation

Along Track Scanning Radiometer

The Australian involvement in the Along Track Scanning Radiometer (ATSR) program continues. The instrument is a joint effort between the Rutherford Appleton Laboratory in the U.K., C.R.P.E. (Centre de Recherches en Physique de l'Environnement



Preliminary work for the ATSR program. A radiometer on board the CSIRO research ship, the RV Franklin, *is used to test current techniques for determining sea surface temperatures from space.*

Terreste et Planétaire) in France and CSIRO. The ATSR is a new generation infrared and microwave radiometer designed to measure sea surface temperature from space with an accuracy of better than 0.3°C. The instrument will be launched from Kourou in French Guyana by the European Space Agency (ESA) on their first remote sensing satellite ERS-1. Launch is currently planned for late 1990.

The Division is taking a leading role in the pre-launch activities required for deriving sea surface temperature from the satellite data, organising ship and airborne campaigns for the validation of the satellite products and developing the means for comparing infrared data and products from two or more different satellites.

The preliminary work for ATSR includes the use of ship-borne radiometers to test the current techniques for deriving sea surface temperatures from space. Two cruises on the *RV Franklin* have been undertaken, one in the Coral Sea and one off the west coast of Australia. Joint studies of air-sea interaction and the energy budget of the sea surface have been started with the CSIRO Divisions of Environmental Mechanics and Oceanography, the

University of Tasmania and Curtin University. Radiometer and coincident satellite data have been collected southeast of Papua New Guinea and on the equator north of Australia. Analysis of these data sets is under way.

Research efforts have been concentrated in two main areas — development of ATSR scientific objectives and applications of AVHRR data. A simulated ATSR data set has been completed for the Rutherford Appleton Laboratory science team and other data users to assess the usefulness of ATSR data in various applications.

Atmospheric Pressure Scanner

The measurement of surface pressure from space is one of the major unsolved problems in satellite remote sensing. Active systems using highly stable lasers tuned to an absorption line of oxygen offer the most promise in the long term, but presently face many technical problems. More attractive in the short term are passive systems such as the near infrared system under study at the Division. The absorption of radiation by oxygen is monitored and this permits the mass of oxygen along the ray path through the atmosphere to be inferred. Because oxygen is well mixed in the atmosphere, the oxygen mass is directly related to atmospheric pressure. In this system sunlight reflected from the earth's surface will be sampled.

The Division has put forward the Atmospheric Pressure Scanner in response to a call from the Japanese National Space Development Agency (NASDA) for foreign sensors for the ADEOS satellite which is to be launched in 1993.

Two prototype instruments have been constructed. Extensive numerical modelling suggested the construction of a high resolution spectrograph and established the precision with which the aerosol loading and temperature profile of the atmosphere must be known in order to recover surface pressure with an accuracy of 2 hPa.

Based on these results, a prototype high resolution spectrograph was developed, using a holographically recorded, concave diffraction grating designed and manufactured by the optics group at CSIRO Division of Materials Science and Technology. Preliminary tests with the prototype support the modelling results and have provided the basis for the design of a rugged, stable instrument for use in the research aircraft.

The CSIRO Office of Space Science and Applications (COSSA) has funded the development of the second prototype. The instrument is being developed jointly by the Division, the CSIRO Division of Materials Science and Technology and Auspace Pty Ltd.

Construction of the optical housing of the prototype Atmospheric Pressure Scanner on a computer controlled mill in the Division workshop.

Other instrumentation

Preliminary work has been done on two other instruments for meteorological satellites: a cloud size analyser and a high speed image analyser.

It is well recognised that the radiation fluxes to and from the earth depend not only on the cloud amount but also on the degree of fragmentation of the cloud. The purpose of the cloud size analyser is to supplement the data currently available from instruments such as the AVHRR with the size analysis of cloud fields using high speed image analysis on board the spacecraft.

Reliable size information can also be recovered by applying modern image analysis techniques to satellite imagery. This analysis can be performed in real time by a dedicated processor on board a satellite. The processor needs only current technology and would be a low cost supplementary package for one of the existing instruments.

Satellite reception and commercial activities

The original NOAA (National Oceanic and Atmospheric Administration) satellite reception component of CSIDA was designed by Divisional engineers and constructed in the electrical and mechanical workshops. The system was installed in 1983 and has run successfully ever since, acquiring data from up to six satellite overpasses per day.

This system became the prototype for a commercial development venture undertaken jointly by the Division and the firm of PCM Electronics Pty Ltd. The venture proved successful with PCM selling systems to the Bureau of Meteorology in Melbourne, the WASTAC consortium in Perth and the NASIS consortium in Townsville.

Image processing system

Experience in operating the image processing component of the original CSIDA facility coupled with the need to find a cost-effective expansion path to meet future processing requirements led Divisional scientists to build and market an improved image processing system based on the need for increasing speed at lower cost, software rather than hardware solutions, portability, enhanced display systems and improved user interactions.

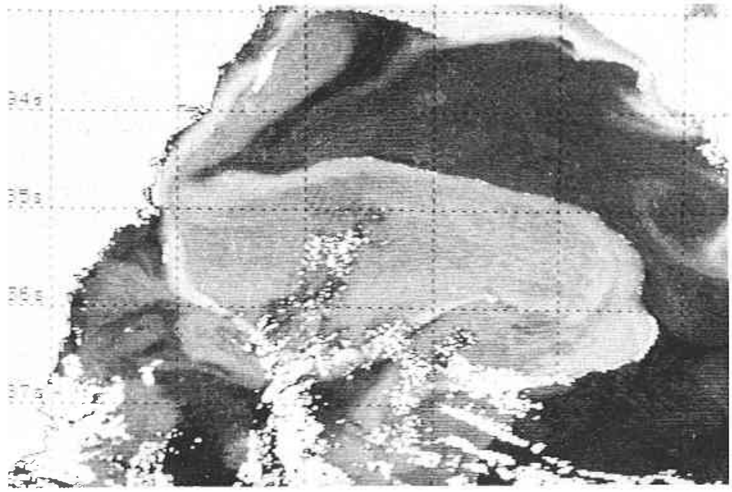
The system was built and marketed as part of a joint venture between the Division and The Dindima Group Pty Ltd. Although sales to date have been limited to only four units, the system has proved the advantages of the concepts on which it was based and has thus pointed the way to present and future developments in this particular technology. The exercise has also given the Division experience in commercialisation.

Value-added products

Ever since the commissioning of the CSIDA facility in January 1984, the Division has been inundated with outside requests to supply satellite images or data enhanced in various ways to highlight features or to extract information of significance such as sea surface temperatures or vegetation indices. The past three years have seen the establishment and progressive improvement of a service to meet these requests.

The service operates commercially and is able to support its own programmer and general expenses. The range and quality of its products have improved as procedures and techniques developed in various Divisional research programs have been progressively incorporated into its operational code.

A recent innovation has greatly improved product distribution. It allows customers to use personal computers to access a data base of requested value-added products via a dial-up modem. Selected image data can then be transferred to their local system which will display or print the information in the form of a full-colour plot which is a faithful representation of the original image.



A CSIDA image showing sea-surface temperature off the New South Wales coast. The darker the area, the warmer the water.

Current and future directions

A continuing strong demand for systems which provide the reception and processing capabilities of CSIDA encouraged the Division to explore new avenues for commercialization. The exercise culminated with a proposal to establish a new company which would market turn-key reception and processing systems based on the evolving CSIDA technology and a range of value added products. Ownership of the company would be shared between CSIRO, which would contribute its expertise in the area and several Australian-owned companies which would contribute management and marketing expertise as well as capital to undertake commercial development.

The joint venture partners would be dedicated to the strategic development of systems over the next decade. The proposed new company would be uniquely placed to incorporate in its operational systems those techniques and procedures which emerge from CSIRO's ongoing research in the area of remote sensing. Negotiations are continuing.

Water Resources

Introduction

As a dry continent with a great variability in rainfall, it is appropriate that considerable emphasis should be given to the hydrologic aspects of Australia's climatic system. This has resulted in the establishment of the Water Resources Program within the Division of Atmospheric Research.

The program aims to identify important mechanisms affecting regional and global climate as they apply to the water budget. Practical means of forecasting droughts are being derived and research is being done to improve understanding of severe storms and rain-bearing systems. The results of this work will be very important for engineering schemes and precipitation evaluation.

The drought and surface moisture studies both relate to climate and land use problems and employ numerical modelling techniques on quite different space scales. These techniques and quantitative precipitation evaluation should realise a strong similarity in physical parameterization schemes. The surface moisture study has a major field observational component with emphasis on extensive irrigation areas in semi-arid Australia.

The studies related to mesoscale convective systems and mid-latitude winter storms are predominantly observationally based and involve detailed analysis and interpretation of comprehensive data sets from tropical and mid-latitude regions.

Drought studies

This research aims to identify the causes of drought initiation and cessation and to develop a testable drought prediction scheme. Research is being pursued via general circulation models and a major model development program has been completed recently. One aspect of this program involved updating of the soil hydrology parameterization and its evaluation in terms of the diurnally varying regional climatology at individual model gridpoints.

Emphasis is now being placed on assessment of the impact of Pacific Ocean sea surface temperature anomalies as drought precursors, using the updated general circulation model. Observations have identified major droughts in Australia with such anomalies, particularly El Niño events. Very realistic droughts have been obtained in the model for Australia and other regions, as well as enhanced rainfall associated with El Niño.

Future experiments will explore the relationship between the spatial distribution of drought and that of the anomalies.

Timely drought predictions resulting from sea surface temperature anomalies require that the anomalies be forecast. The ability to predict El Niño events is therefore central to the drought project. International research on this topic has used observed winds to force a numerical model of the equatorial Pacific Ocean. However, recent observations have shown that the response of the equatorial Pacific is also dependent on the polewards heat transport by the Kuroshio Current. The strength of this current is thought to depend on westward propagating Rossby Waves in a way that is poorly understood. Hence, the numerical model of the Pacific Ocean being developed as part of the drought project is being forced not only by the observed surface wind field but also by the observed strength of the Kuroshio Current. Assessments of the model using the 1982/3 El Niño-induced drought in Australia are planned.

Pacific Ocean currents north of Australia

El Niño

Due to their very large heat-holding capacity, the oceans play a major role in driving the atmosphere. A persistent temperature anomaly in the oceans of only 1 or 2°C can cause appreciable disruptions in the atmospheric circulation. The best known anomaly of sea surface temperatures is El Niño.

El Niño forms part of a large scale atmospheric phenomenon. Air circulates east-west along the equator in cells centred over the great oceans. The strongest such circulation occurs above the Pacific. Warm, moist air rises over the Indonesian region resulting in cloud and rain. The air rises to the upper troposphere and travels eastwards, to sink towards the cold waters off Peru. The descending air creates an oceanic dry zone off South America. Under normal easterly trade wind conditions, the sea level is about 40 cm higher in the west than in the east. When these winds slacken, the drag on the ocean surface diminishes and warm water is transported back to the east and interferes with the usual upwelling of cold water off Peru. This is the birth of an El Niño. Drought spreads across most of Australia bringing with it immense dust storms, bushfires and losses in agriculture and livestock production.

Long sets of meteorological data show the existence of a coupled ocean-atmosphere system that irregularly switches to the El Niño state every 2 to 7 years. The alternation is called the Southern Oscillation and involves the see-sawing of the atmospheric pressure level between points in the western and eastern Pacific. Normally pressure in the west is lower than that in the east. However during El Niño events the opposite condition prevails. El Niño and the Southern Oscillation are different manifestations of the same phenomenon which is often referred to as ENSO.

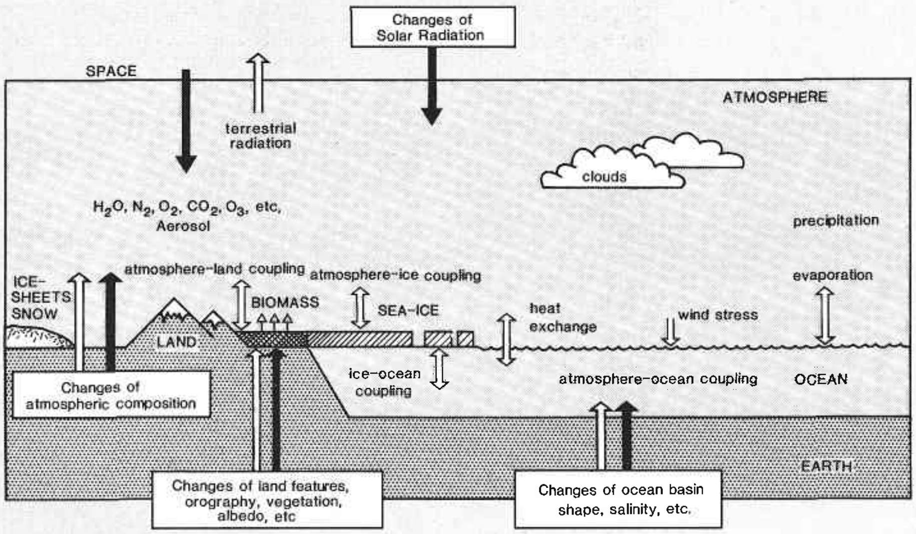
La Niña is the reverse cycle of El Niño. It is associated with higher rainfall and a greater number of cyclones over Australia.

General circulation models

Recent emphasis has been on developing general circulation models. The original two level model has been modified to four levels so that a more accurate specification of near surface properties can be obtained for use in driving a coupled oceanic model.

Data from one year have been generated with the atmospheric model and this is being used to tune a three layer oceanic model. The latter model contains a variable depth mixed layer and a thermocline layer, both of which include advection and upwelling. The third layer is static and relaxes to observed temperatures. This model should permit integrations of the coupled oceanic–atmospheric model for 10 year periods. This is adequate for many climatological studies.

Exploratory runs with the coupled model are about to commence. Success with this model should provide crucial guidance for the ultimate aim of coupling the atmospheric general circulation model with a multi-level primitive equation oceanic general circulation model. Using output from a 10-year integration with the two level model, the conditions governing the production of naturally occurring drought in the model have been analysed for a number of geographical regions. Naturally occurring drought is considered to result from nonlinear interactions of the climatic system. As such it is inherently unforecastable. Fortunately, the model results and subsequent examination of observed rainfall variations in Australia, confirm that such droughts are restricted to small areas and usually last for only one year.



The major processes influencing the complete earth–ocean–atmosphere system

The two level atmospheric model has been improved by replacing the bucket soil hydrology by a two-layer scheme, which is far more sensitive. The model is now being run in the diurnal mode and improvements have been made to the way in which near surface moisture and temperature are derived. The overall performance of the model has improved and detailed examination of diurnal and inter-diurnal variability has revealed a wealth of climatic information. The details of this variability provide encouragement for the use of the model in planned experiments. These results also highlight some problems in simulations which may not be generally appreciated. This version of the model has now been superseded by the four level model which will be used in a series of experiments designed to provide insight into the characteristics of drought, particularly in the Australian region.

Due to the dominant influence of El Niño events in the creation of Australian droughts, an oceanic model of the Pacific extending from $30^{\circ}N$ to $30^{\circ}S$ is being developed. The model initially will be entirely wind driven using observed data for the validation part of the assessment. A simple atmospheric model will be used to generate the wind data when the model operates in a predictive mode. This simple coupled model will be used to predict sea surface temperature anomalies associated with El Niño events, permitting these anomalies to be inserted into the four level general circulation model. By this means it should be possible to predict the large scale droughts occurring over eastern Australia during El Niño events.

General circulation models

In some areas of science it is not possible to carry out direct experiments on the subjects of interest. The global atmosphere is an example of this and computer-based general circulation models are used for investigations.

Changes in heating patterns due to increased emissions of greenhouse gases will influence all other elements of climate including rainfall, cloudiness, frequency of cyclones, mid-latitude storm tracks, frosts, snowfall and sea-ice. For a complete treatment it is necessary to consider the whole globe from the surface to well into the stratosphere, and all the major processes influencing the complete earth-ocean-atmosphere system. General circulation models are designed to satisfy these requirements.

General circulation models involve solving a set of at least six highly non-linear partial differential equations on a spherical grid at different levels. Six equations are needed to solve the six variables: pressure, temperature, humidity and the three components of velocity. A horizontal grid with a mesh of 500 km, for example, gives about 35 points over Australia. Some 2 000 points cover the globe. Thus, for a 15 vertical level model, the three dimensional grid contains 30 000 points at each of which the equations have to be solved for the model to be advanced one time step. Using the most powerful of modern computers, typically ten minutes of processing time is needed for one model day; five hours for each month.

General circulation models have many applications and have been used for some time for day to day weather forecasting.

Middle atmosphere modelling

Some detailed development of the model, which extends from the surface to 100 km, is continuing. In addition to allowing diurnal variability in the atmosphere, the diurnal variability of the land surface temperature is now permitted. The gravity wave drag parameterization scheme of the British Meteorological Office has been permanently implemented in addition to the previously used

Lundzen drag scheme. However, the mesospheric wind systems, particularly in the southern hemisphere, have proved to be very sensitive to the parameters defining the intensity of dissipation associated with these schemes. This has caused considerable difficulty in obtaining a final climatology due to the time consuming nature of assessing the impact of changes to this dissipation. This process of adjustment is now nearly completed and it is next proposed to analyse the interaction of the breaking internal gravity waves with the tidal structures in the model mesosphere.

Surface moisture impact on climate

A long term investigation of the impact of surface moisture discontinuities on the behaviour of the lower atmosphere and ultimately regional climate, has commenced in conjunction with Colorado State University, USA. Aircraft experiments over irrigation areas in the semi-arid regions of north east Colorado have revealed significant differences in the planetary boundary layer structure over dry and irrigated sectors.

These differences are consistent with the presence of inland sea breeze-like circulations known as non-classical mesoscale circulations. These circulations are not readily observed because of air flows from the nearby mountains as well as large scale atmospheric circulation.

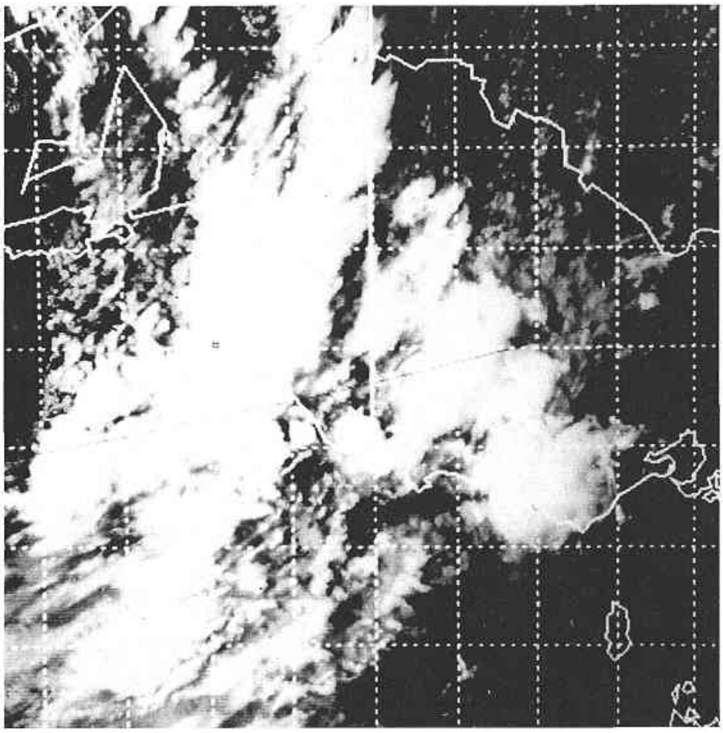
Another field experiment involving both aircraft and satellites was conducted in south-east Colorado over snow soil discontinuities. The aim of this experiment is to identify non-classical mesoscale circulations and to relate these to those expected over irrigated areas. Appropriate areas in eastern Australia are now being identified for study.

An evaluation is being done into the impact of wet soil and vegetative canopy surface temperatures on Bowen ratios and boundary layer depth as a function of latitude and season. Modifications to the evaporation parameterization used in models, specifically in climate studies, are being assessed.

Dynamics of mesoscale convective systems

Analysis of data from the field phases of the Cold Fronts Research Program has been completed. This collaborative project involving the Division of Atmospheric Research, the Bureau of Meteorology and several Australian universities has resulted in a new understanding of the genesis of the summer-time cool change.

A conceptual model has been developed which explains the behaviour and structure of the main frontal types. The roles of evaporative cooling and the influence of the coastline in modifying the cool change are now understood. Results have been communicated to operational forecasters via a series of workshops



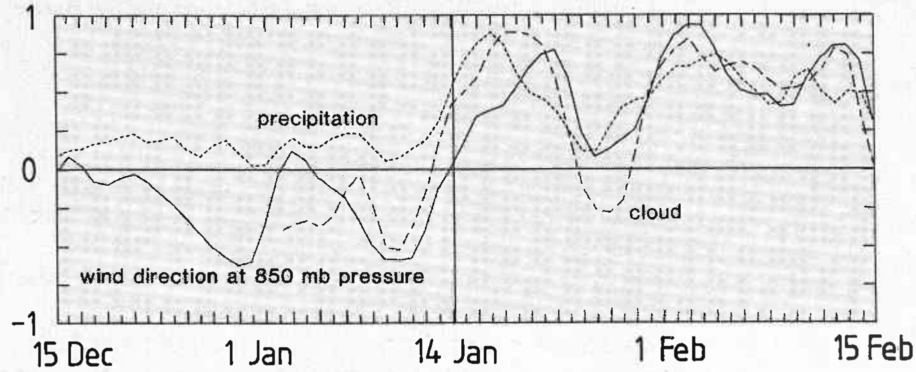
A CSIDA image showing the eastward progression of a cold front across southern Australia.

and through close liaison with colleagues in the Bureau of Meteorology Training School and Monash University.

EMEX

In the tropical regions of the world and particularly in the oceanic region to the north of Australia, the atmospheric hydrologic cycle is dominated by mesoscale convective systems. Thus in 1987 the Division of Atmospheric Research in collaboration with the U.S. National Center for Atmospheric Research (NCAR), several U.S. universities and the Australian Bureau of Meteorology, participated in the Equatorial Mesoscale Experiment (EMEX). The purpose of EMEX was to define the input of cloud systems to the vertical heating rate profile in the tropical atmosphere. The correct representation of this profile is a fundamental requirement for both global and regional climatic and forecasting models. It is this heating profile which essentially drives the global climatic system.

The observational phase of EMEX took place during January and February 1987 and eight cloud systems were investigated by appropriately instrumented research aircraft including the CSIRO F-27. Collaborative analysis of the resulting data sets is now under way. Concurrent with the EMEX project were two other major observational programmes, the Australian Monsoon Experiment (AMEX) and the Stratospheric Tropospheric Exchange Project (STEP).



Daily time series of rainfall and cloudiness over northern Australia

Australian summer monsoon

Observational and theoretical studies of the Australian summer monsoon have continued. The onset process during AMEX was extensively studied. A very clear onset occurred on 14 January with a dramatic increase in rainfall, cloudiness and low level westerly winds. This onset date was more than two standard deviations later than the thirty year mean of 24 December. This was a direct reflection of the suppressing effects that the 1987 El Niño event produced throughout the Australian region.

The predominant fluctuations in the intensity of the monsoon are at low frequency, that is greater than a 20 day period. Well defined 40–50 day oscillation events were identified in the Australian region. The major break on about 27 January was associated with the eastward traversal of the downward branch of one such event.

Considering the marked influence the 40–50 day oscillation has on the Australian monsoon, a theoretical explanation of the oscillation is desirable. A model developed at CSIRO reproduces most of the features of the observed oscillation and is unique in that the amplitude of the disturbance is predicted in a self consistent manner. The basic hypothesis of this model is that the tropical atmosphere is conditionally unstable. A large-scale disturbance grows due to the instability. However as it gains amplitude it reduces the instability through vertical transport of heat. This stabilisation occurs in the manner necessary for slow eastward propagation to occur. The relevance of this mechanism to the observed oscillation is still under investigation.

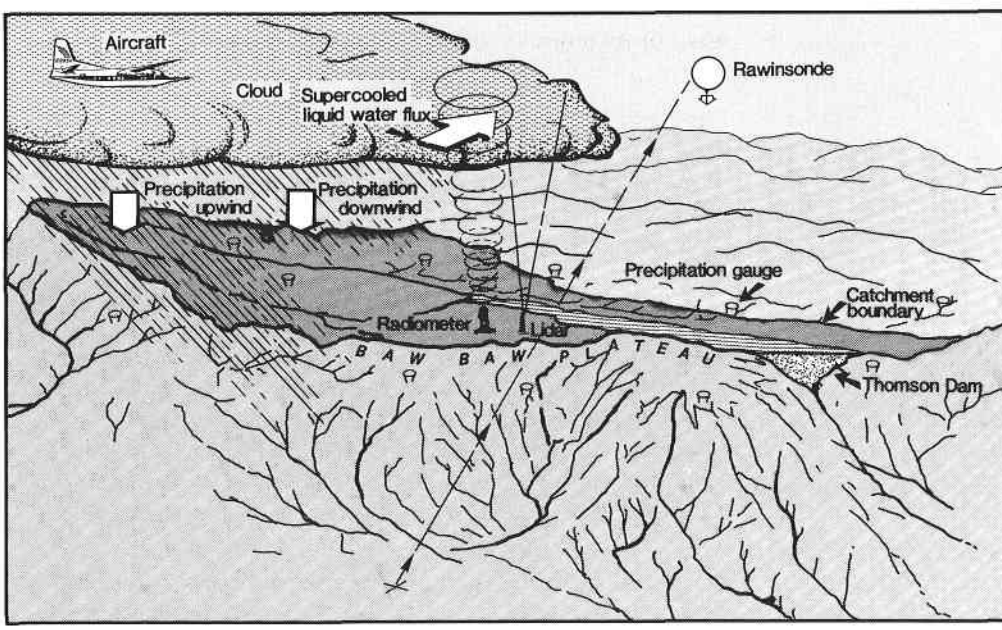
The Australian Winter Storms Experiment

The Australian Winter Storms Experiment (AWSE) will be conducted during July and August, 1988. The experiment is sponsored by the Division and has also received support from the

Melbourne and Metropolitan Board of Works (MMBW), the Australian Urban Water Research Association and the Bureau of Meteorology. Overseas support comes from the US National Science Foundation, the National Oceanic and Atmospheric Administration and the Desert Research Institute of Nevada.

AWSE aims at improving a cloud seeding experiment which will be conducted by the MMBW over the next five years. It is designed to show whether, and to what extent, precipitation can be increased over the major Thomson Dam water supply catchment. The Division will act as scientific consultants for the conduct and analysis of the experiment. A wide range of instrumentation and observations will support a study of the condensed-phase water budget of the clouds over, upwind and downwind of Baw Baw Plateau. Of particular concern is the relationship between the amounts of precipitation and the super-cooled liquid water that flows across the Plateau within the clouds. This liquid water would be the main source of any additional precipitation which could come from cloud seeding. The amount of liquid water may represent the potential increase in precipitation from cloud seeding. Information on when the water is present will indicate when cloud seeding should be conducted.

The Australian Winter Storms Experiment



Geophysical fluid dynamics

Geophysical fluid dynamics laboratory

The geophysical fluid dynamics laboratory carries out a variety of experiments modelling atmospheric phenomena involving density stratified and rotating fluids. An effective method of measuring fluid speeds in these experiments is to use neutrally-buoyant particles as tracers. A system which can do this for a whole field of motion which rapidly changes with time has been developed. The fluid is seeded with small polystyrene beads and is then illuminated by a thin but intense sheet of laser light. The fluid motion in this sheet of light is viewed by a video camera and the positions of the visible beads in successive frames are recorded by a computer using "imaging boards". This enables calculations of velocity fields, showing how the motion evolves with time.

The system is being designed for use with turbulent plume experiments as a model for bushfires. During the development process it has been used with simpler flows such as stratified flow past three-dimensional obstacles. The formation of upstream blocking and downstream eddies at low levels can be clearly visualized and measured with the new system.

Fluid transport through Bass Strait

As part of an air-sea interaction program, an experiment was designed to measure and analyse the flow of sea-water through Bass Strait. This is important for an understanding of oil spills and transport of dissolved and suspended material.

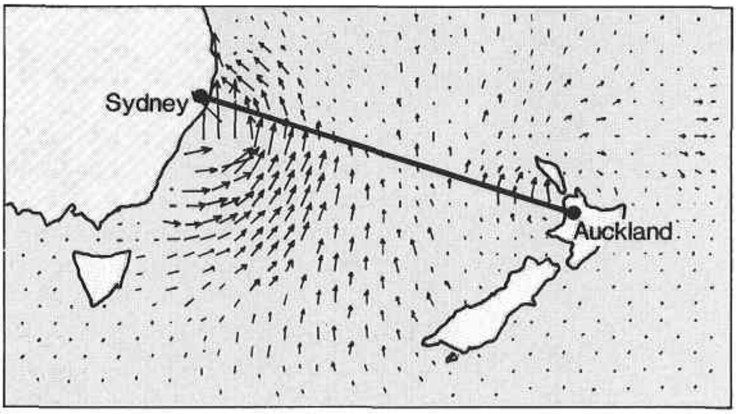
The experiment was a collaborative project with the Victorian Institute of Marine Sciences with assistance from the CSIRO Division of Oceanography. Two sections of current meters were deployed between Cape Otway and King Island and King Island and Hunter Island, together with a number of tide gauges around Bass Strait. Data were also obtained from Bureau of Meteorology wind stations. It was found that in winter, through-flow mostly occurs in surges from west to east lasting from two to three days. This coincides with the south-westerly airstreams which follow the passage of atmosphere cold fronts across the region. The flow is forced by this air stream within and to the west of Bass Strait.

Ocean current transport

An innovative study of ocean current transport involved an old Morse-code submarine cable which was laid under the Tasman sea in 1912. The 2 270 kilometre length of insulated wire carried telegraph messages between Sydney and Auckland until 1967.

Oceanographers have known for some time that the flow of sea water across cables induces small voltages. Seven years of cable-voltage data were analysed using mathematical modelling.

The monthly average cable voltage was found to correlate with the mean sea level at Sydney, suggesting that the cable was in fact responding to ocean currents. However there were problems associated with extraneous variations due to action of ocean eddies, variations in the earth's magnetic field and short circuiting of the signal by sediment and rock beneath the cable. This meant that correlations between voltage surges and documented ocean movement could not be found. Due to a combination of conductivity and depth effects, the cable was much more sensitive to current movements near Sydney than elsewhere. Therefore it was concluded that local effects override any signal generated by large scale ocean movements.



The length of each arrow shows the sensitivity of the cable to ocean current of unit speed at that point.

Coastal currents

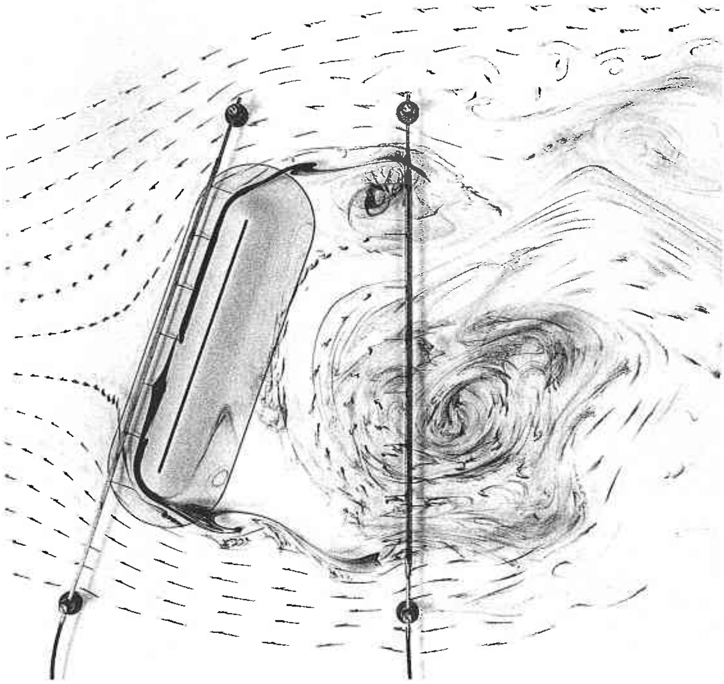
Current research in the Division aims at understanding the properties and constraints operating on the different forms of coastal currents. Of particular interest is the ability to transport heat poleward. This may explain why the Gulf Stream off the Atlantic coast of North America appears to have a much greater influence on the climate of that ocean than the corresponding Kuroshio Current has on the Pacific Ocean.

Effects of topography on atmospheric flows

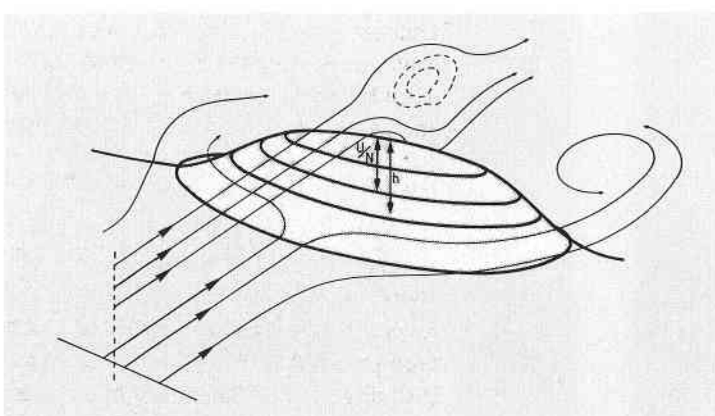
Previous work on stratified flow over topography of substantial height has been extended in several ways. Laboratory studies of flow past three-dimensional barriers which model a mountain range have been carried out to show the relevance of two-dimensional studies to more general situations. For sufficiently high topography, low-level blocked flow passes around the obstacles and separates, forming eddies in the wake. This downstream flow is essentially unsteady, which affects flow impinging on obstacles further downstream. Upper level flow passes over the obstacles as if they were nearly two-dimensional. This study has been used to establish a general framework for laboratory modelling of flow over realistic complex terrain.

Flow over topography of substantial height has a very different character from flow over topography of small height. In the former, flow is essentially non-linear and has a hydraulic character resembling that of flow over rocks in a shallow stream. The drag of topography on the fluid increases dramatically when this regime is reached. Hydraulic models of stratified flow have been constructed to explore and describe this process and these have been compared with laboratory observations. Understanding of this phenomenon has reached the stage where applications of these hydraulic models to real situations can now be made.

A laboratory study of the topographic effects of Antarctica on the mean southern hemisphere circulation has been carried out. The close similarity between flow patterns in a rotating tank and the mean atmospheric flow pattern at a height at which the pressure is 700 mb implies that the important dynamical factors in the atmosphere are the same as those in the tank. This suggests that the governing principles are potential vorticity conservation and flow separation from topographic features, producing large separation eddies.



The effect of a three-dimensional barrier on low level stratified flow. The addition of a dye stream to the water enables the flow pattern to be clearly seen.



Upper level stratified flow over a simple three-dimensional barrier

Activities

Technology transfer

The Division of Atmospheric Research collaborates and exchanges information with many organisations both within Australia and overseas. Many examples are described elsewhere within this report.

In support of its research programs, the Division has been actively engaged in devising and developing new instruments and methods for studying aspects of weather, climate and air pollution. The potential for commercialisation of our inventions has become more and more obvious and during the past three years a number of technology transfer projects have occurred.

Commercialisation of CSIDA

The satellite data acquisition and analysis facility developed at the Division is being marketed in the form of meteorological satellite receiving stations, together with image processing workstations. A detailed description of the commercialisation of CSIDA appears in the Remote Sensing section of this report.

Electrical read-out meteorological barometer

A barometer of very stable long-term performance, with electrical read-out suitable for automatic logging of data was developed in support of the Division's cold fronts research program. The barometer appears to fill an international market niche and is being considered for manufacture by a Melbourne based scientific instrument company.

Cylinders for the stable storage of reference gases

In collaboration with the Division of Materials Science and Technology, the Division is contributing expertise towards the development of special gas cylinders with stable, low contaminant internal surfaces. A potentially large international market is anticipated within the semiconductor industry and atmospheric chemistry research. A licence agreement is being negotiated with a Melbourne manufacturer, through Sirotech.

TV signal distribution

Advice, engineering assistance and testing services have been provided to the Melbourne company, On-Site Aerial Service in the development and manufacture of products associated with TV signal distribution in large installations. Currentiy these products are obtained from overseas manufacturers and the aim is to manufacture them locally with a potential for export. The Division of Applied Physics has participated in some product-certification tests.

Laser ceiliometer

A low power Nd-746 lidar is being developed in collaboration with the Tasmanian Development Authority. The lidar is suitable for the measurement of cloud height and for assessing visibility.

Mechanical products

Several items developed by the Division during the manufacture of mechanical components are being considered commercially. These include a rotary welding positioner and a castor wheel assembly of adjustable load and suspension range.

Consultant services

The Division has a very broad base in theoretical and experimental techniques which are applicable to the analysis of commonly encountered environmental issues. These include

- particle transport modelling
- atmospheric flow modelling by fluid tank experiments
- NATA-certified anemometer calibration service
- satellite remote sensing of clouds, sea surface temperature, and land surface for vegetation and geological studies
- transportable lidar facility for tracking airborne material such as industrial smoke plumes, toxic gases and dust
- mobile air chemistry laboratory for the analysis of urban atmospheric pollution
- computer based climate modelling

A brochure detailing facilities and potential commercial applications for the use of Division expertise in the above areas is being developed.

Facilities Group

The Facilities Group provides engineering and computing support to the Division's research programs. It designs and develops specialised scientific instrumentation and participates in the transfer of technology to industry. Computing services are offered via extensive local facilities and Csironet. The Group also manages and maintains buildings, facilities and services.

Engineering

The design, development and manufacture of advanced scientific instrumentation to support the Division's experimental research programs have provided considerable challenge to engineering staff. The Engineering Group's activities have expanded with the increasing emphasis on the commercialisation of CSIRO–developed technology.

Some of the major instrument development tasks undertaken during the reported period include the automation and computer control of gas chromatographs, integration of image processing workstation hardware, on-going development and enhancement of NOAA and GMS satellite reception facilities, fluid tank atmospheric modelling instrumentation, laser systems as well as extensive instrumentation associated with atmospheric chemistry research. A proposed satellite borne radiometer is being developed for the remote measurement of ground surface atmospheric pressure.

Field programs requiring significant engineering support included air quality studies in the Latrobe Valley, continued work associated with the Australian Baseline Station at Cape Grim and research installations aboard the *R.V. Franklin* and Fokker F-27 aircraft.

The provision of engineering support to industry via consultant services and direct assistance in the design and development of new products have resulted in successful commercial collaboration detailed elsewhere in this report.

Computing

The Computing Group is responsible for operating the local computers and network and for providing a support service to all computer users. The Division is one of the major users of computers in CSIRO. Great demand has been placed on the Organisation's Cyber 205 supercomputer and on the Csironet network for atmospheric modelling. Six local minicomputers are in operation as well as about seventy personal computers. An Equinox digital data switch was installed in 1987 to provide access to all facilities from any terminal or PC on site.

During the past three years the Division has been involved in shaping the Cyber 205 service and has played a major role in ensuring that usage is free to Divisions so that the machine is fully utilised. The Cyber 76 service on Csironet has been phased out and work has been transferred to the Cyber 205 and Cyber 180 machines.

The Computing Group manages the Csironet micronode and peripherals for users and oversees the use of the Division's file storage allocations. In 1985 a Hewlett-Packard A900 was installed to provide more computational capacity and in 1986 a DEC MicroVAX II was installed to run VAX specific software from other sites and to provide interactive graphics capabilities.

The Group has made a large number of enhancements to the local machines and the network connecting them. It has also continued to provide substantial support services to the CSIDA facility.

The number of personal computers on site has grown rapidly. The Computing Group is involved in advising users on hardware and software purchases, installation, usage and faults. The Group also provides support services to conference organisers.

The Computing Advisory Committee has prepared a five-year plan for computing in the Division. This plan involves a major local host machine running the UNIX operating system, a local area network, and either continued access to a CSIRO supercomputer or a mini-supercomputer on site. The Division has received a grant from the Major Items of Equipment budget to enable the purchase of the host and network in 1988-89.

Scientific Services Group

The Scientific Services Group supports the Divisional research effort and helps maintain contact with the scientific community and the public at large.

Explaining the research the Division does as well as emphasising the importance of the work is an essential role of the Group. Activities include reporting to the Institute and the Government, information exchange between Divisions, communicating with scientific users of the Division's research and keeping the general public informed about scientific advances and topical issues. Communication within the Division is very important and regular newsletters, bulletins and research reports are produced.

Management and scientific administrative tasks are also performed by the group and these have been described in detail in the previous report.

The Division has an extensive library which makes full use of the CSIRO Library Network. An integrated on-line automated library system (CLINES) was introduced during 1986.

Photography and graphic services are available for scientific publications, conference presentations, lectures and special displays.

Conferences and Workshops

The Division of Atmospheric Research fosters the exchange of scientific information by supporting a wide range of conferences and workshops. A major conference during the reporting period was Greenhouse 87.

Greenhouse 87

The main objectives of this conference were to encourage scientists to assess the potential impacts of climate change of the kind possible due to greenhouse warming and to communicate to the wider scientific and engineering community the current status of the greenhouse theory.

In preparation for the conference a refined climate change scenario was circulated to contributors as a common basis for a discussion of impacts on various industries and sectors of Australian society and activity, ranging from agriculture and wildlife to the insurance and skiing industries. This scenario was largely influenced by that proposed at the international conference at Villach in 1985.

The prepared papers tended to confirm that climatic change of about the magnitude envisaged in the scenario would have very significant, and often deleterious, effects on many parts of the natural and human environment and consequently on Australian economic life.

Some outcomes of the meeting have been:

- The stimulation of climate-impacts research throughout Australia.
- A clearer specification of the requirements of climate modelling work by the wider community.
- Establishment of an awareness of the potential advantages and disadvantages of greenhouse climate change in government instrumentalities and the community at large.
- A contribution to the development of an agreement between the Australian and New Zealand governments to undertake joint research on the issue.
- A contribution to the development of a strong support for such research from the Australian Environment Council.

Greenhouse 87 attracted wide scientific and popular interest and extensive media coverage and was a joint activity by the Division and the Commission for the Future. The edited proceedings will be published in book form as *Greenhouse: Planning for Climate Change.*

Conferences and Workshops supported by the Division

28–30 May 1986
Drought Workshop
Council of Adult Education, Melbourne

18 November 1986
Latrobe Valley Airshed Study Modellers' Workshop
Division of Atmospheric Research. Convenor: P.C. Manins

8–12 December 1986
Mechanisms of Interannual and Longer Term Climatic Variations
University of Melbourne.

17 December 1986
Antarctic Ozone Symposium
Division of Atmospheric Research.
Convenors: P.J. Fraser and R.A. Plumb

1 May 1987
Mesoscale Topographic Effects in the Australian Region
Division of Atmospheric Research. Convenor: P.G. Baines

2–3 July 1987
Meteorology and Physical Oceanography in Australia: Priorities in Research, Operations and Education
Monash University. Convenor: P.G. Baines

24 July 1987
Discussion Meeting on Atmosphere-Ocean Coupled Models
Division of Atmospheric Research. Convenor: B.G. Hunt

30 November – 4 December 1987
The Greenhouse Project: Planning for Climate Change
Monash University. Convenor: G.I. Pearman

14–17 February 1988
Second Conference on Air-Sea Interaction
Merimbula, NSW. Convenor: P.G. Baines

16–24 February 1988
Remote Sensing of Atmosphere and Oceans
Australian Defence Force Academy, Canberra.
Convenor: C.M.R. Platt

29 February – 3 March 1988
Cloud Base Measurement Workshop
Division of Atmospheric Research.
Convenor: C.M.R. Platt

20–21 June 1988
Latrobe Valley Air Shed Study End-of-Study Symposium
Chisholm Institute of Technology. Convenor: P.C. Manins

Administration

The Administrative Group provides personnel and financial services to the Division including recruitment, budgeting, purchasing, word processing, reception, travel and transport facilities.

During the last three years the increasing emphasis on external funding has seen the expansion of commercialization activities and also a greater emphasis on applications to competitive funding schemes. The administration provides high level policy advice to management and research staff and is intimately involved in the negotiation of research agreements with funding bodies and commercial partners.

Due to a major devolution of responsibilities in the personnel and finance areas from the CSIRO Corporate Centre to Divisions, major retraining and reorganisation of administration has occurred to meet these demands.

Visitors to the Division

VIP visits

10 September 1985
Dr Bill Farrell, Manager of Assessment and Research Branch, EPA
Dr Doug Munro, Project Officer, Melbourne Airshed Study, EPA

24 September 1985
Fourth Meeting of the **Divisional Advisory Committee**

15 November 1985
Mr Blondeau, Head, Scientific and Technical Cooperation Department
Dr Ullman, International Affairs Division, in charge of Australia, Centre National d'Etude Spatialle (CNES)

21 November 1985
Senator Brian Archer, Shadow Minister for Science

13 December 1985
Senators Sanders and Vigor

16 January 1986
Hon. Barrie Jones, Minister for Science

20 January 1986
Mr Hans Eisen, Director-General, Department of Industry, Technology and Resources
Dr Murray Frazer, Project Director, Technology and Innovations, ITR

21 January 1986
Dr Roger Smith, Bureau of Meteorology
Dr Greg Holland, Bureau of Meteorology

23 January 1986
Mr Robert W. Jemison, Divisional Manager, Scientific Instruments Division, ICI Australia Operations Pty. Ltd.

23 January 1986
Mr Terry Kelly, KEL Aerospace

5 February 1986
Dr Neville Fletcher, Director, Institute of Physical Sciences

14 February 1986
Dr Don Thompson, New Zealand Meteorological Service

4 April 1986
Fifth Meeting of **Divisional Advisory Committee**

17 April 1986
State Remote Sensing Committee

28 April 1986
Ms Fiona Hamilton, Victorian Department of Conservation, Forests and Lands

1 May 1986
Mr Mike Fosberg, Riverside Fire Research Station, Los Angeles, USA

7 May 1986
Mr C. Veenstra, Director, Division of National Mapping
Dr D. J. Grey, Station Director, Australian Landsat Station

18 June, 1986
Mr Phillip Adams, Media Consultant

17 July 1986
Natural Environment, Renewable Natural Resources Standard Committee (NERNR)

22 July 1986
Professor P.D. Bhavsar, Director, Space Applications Centre, Indian Space Research Organisation

22 July 1986
European Communities Delegation
Dr Philippe Bourdeau, Dr Ugo Miranda, Mr Luciano Cao and **Dr Alan Jones** of DITAC

19 August 1986
Dr Ian Torrens, Organisation for Economic Cooperation and Development (OECD)

3 September 1986
Mr. M. Tanke, Elsevier Publishing

12 September 1986
Mr Julian Beale, MHR

24 September 1986
Dr Dixon Butler, NASA
Dr Karen Miller, NASA

3 October 1986
Dr Ian Bailey, Zoology Department, Monash University

10 October 1986
Dr Alex Buchanan, Centre for International Research Cooperation (CIRC)

10 November 1986
Hon. B. O. Jones, Minister for Science

13 November 1986
Prof. Qing Lin Zheng, State Meteorological Administration, P.R. China

4 December 1986
Mr Tom Warwick, Liberal Candidate for Dunkley

5 December 1986
Dr Peter Rowntree, Meteorological Office, Bracknell, UK

16 December 1986
Sixth Meeting of **Divisional Advisory Committee**

17 February 1987
Chinese Meteorological Delegation, SMA Academy of Meteorological Science

19 February 1987
Mr Abdul Karim Heneidy, Meteorology and Environmental Protection Administration (MEPA)
Dr Daryl Lacey, Australian Adviser on Environmental Regulations to MEPA

18 March 1987
Mr David Nixon, Minenco Pty Ltd

2 April 1987
Dr Y. Horikawa, National Space Development Agency of Japan (NASDA)

12 June 1987
Mr Digby Gascoigne, Department of Arts, Heritage and Environment

26 June 1987
Seventh Meeting of **Divisional Advisory Committee**

29 July 1987
Dr Tony Gregson, Member of CSIRO Board

25 September 1987
Mr Colin Tudge, BBC Science Show, UK

9 November 1987
Technical Standing Committee

16 November 1987
Dr Joji Tabata, Dr Shigeo Yamada , Dr Shoju Matsubara, National Space Development Agency of Japan

3 December 1987
Dr K. McCracken, Director, COSSA

17 December 1987
Eighth Meeting **Divisional Advisory Committee**

7 January 1988
Hon. Neville Wran, QC, Chairman of CSIRO

15 January 1988
Dr Roy Green, Director, Institute of Natural Resources and Environment

22 January 1988
Dr Brian Mapes, University of Washington

8 March 1988
ASIA members

16 March 1988
Japanese delegation from the Science and Technology Agency
Dr Joichi Takagi, Director, Disaster Prevention Research Division, Research and Development Bureau, Science and Technology Agency.
Mr Yoshifumi Kuroda, Japan Marine Science and Technology Center
Mr Yohsuke Hoashi, Staff Writer, Science Department
Mr Kenkichi Hirose, First Secretary, Embassy of Japan, Canberra

18 March 1988
Mr Dave Collins, Alcoa

29 March 1988
Senator Graham Richardson, Minister for the Arts, Sport, the Environment, Tourism and Territories
Mr David Tierney, Senior Private Secretary
Mr Bob Chenowyth, MHR, Member for Dunkley
Councillor Cameron Hogan, City of Frankston

26 April 1988
Mr Tonnes von Zweigberg, Ericsson Radar and Electronics, Sweden
Mr David Nickols, Ericsson Defence Systems Pty Ltd, Canberra

12-13 May 1988
Mr Fred Pearce, News Editor, New Scientist

23 May 1988
Ms Wendy Parsons, Manager, Public Affairs and Communication, INRE

Visiting scientists

9 July 1985
Dr Y. Sugimura, MRS, Tsukuba, Japan

3 October 1985
Dr Gary Meyers, Division of Oceanography

12 November 1985
Dr Richard Walterscheid, Aerospace Corp, Los Angeles

7 February 1986
Dr Richard Dubinski, York University, Canada

21 February 1986
Dr Paul Steele, NOAA, Boulder, USA

27 March 1986
Prof. K. Okamoto, Tokyo Gakugei University

12 May 1986
Dr Michael A. Box, University of New South Wales

13 May 1986
Dr Wolfgang Ulrich, University of Munich

27 June 1986
Dr Alex Craik, University of St Andrews

31 July 1986
Dr Ian N. James, University of Reading

31 July 1986
Dr Scott L. Zeger, John Hopkins University

5 September 1986
Prof. Wilfred Bach, University of Munster

5 September 1986
Dr Paolo Orlandi, University of Rome

9 September 1986
Dr Reinhold Steinacker, University of Innsbruck

24 September 1986
Dr Dixon Butler, NASA

2 October 1986
Dr Charles S. Shapiro, Lawrence Livermore National Laboratory USA.

13 November 1986
Prof. John Allen, Oregon State University

5 December 1986
Dr A.A. White, U.K. Meteorological Office

10 December 1986
Dr G.W. Kent Moore, University of Toronto

15 December 1986
Dr Shigeo Yoden, University of Washington

15 December 1986
Prof. Roger Revelle, Scripps Institute of Oceanography

22 January 1987
Dr Thomas Ackerman, NASA Ames Research Laboratory California

9 February 1987
Dr J. Hogan, Oxford University

11 February 1987
Dr Thomas Hauf, DFVLR, West Germany
Dr Andrew Crook, GFDL Princeton University

2 April 1987
Dr Horikawa

9 April 1987
Dr B.B. Hicks, ARL, NOAA

15 May 1987
Dr David Carruthers, Cambridge University

21 May 1987
Dr Tom Beer, National Bushfire Research Unit, Australia

22 May 1987
Dr Judith Holyer, University of Bristol

25 May 1987
Prof. Murray Salby, University of Colorado, Boulder

25 May 1987
Dr Paul Newman, NASA Goddard Laboratory

17 July 1987
Dr Timothy Bates, NOAA, USA

21 July 1987
Dr David M. Etheridge, Department of Science, Antarctic Division

18 August 1987
Dr Jim Weinman, University of Wisconsin, USA.

7 September 1987
Dr Y. Hayashi and Dr Isobe, Division of Agrometeorology, Japan

14 September 1987
Dr Joe Warburton, DRI, Nevada

15 September 1987
Dr Jeff Weil, Martin Marietta Corp. Baltimore

17 September 1987
Dr Pierre Cellier, Bioclimatologie INRA, France

23 September 1987
Prof. Peter Webster, Pennsylvania State University

1 October 1987
Mr Graham Johnson, CSIRO Division of Fossil Fuels, NSW

29 October 1987
Dr Alan Perry, University College, Swansea

11 January 1988
Dr Ian Watterson, NOAA, Boulder, USA

8 March 1988
Dr Susumu Yamamoto, NRI, Japan

15 March 1988
Dr James A. Moore, NCAR, Boulder, USA

25 March 1988
Dr Tang Dengyin and Zhang Renhua, Chinese Academy of Sciences, Beijing

5 May 1988
Dr Ron Smith, Yale University, USA

8 June 1988
Dr Blair T.N. Evans, Defence Research Establishment Quebec, Canada

International Research Programs

Research at the Division of Atmospheric Research covers a wide range of atmospheric phenomena which impinges on weather, climate and atmospheric pollution. In performing this research, scientists maintain close contact with colleagues both nationally and internationally. Although many of these interactions are directly institute to institute and scientist to scientist, there are a number of international research programs to which our scientists contribute and cooperate with others in setting goals and tasks for the future.

The two main international bodies relevant to atmospheric science are the International Association for Meteorology and Atmospheric Physics (IAMAP) and the World Meteorological Organisation (WMO). The Chief of the Division of Atmospheric Research, Dr G. B. Tucker, has been President of IAMAP since 1988. Another organisation with an interest in atmospheric science in terms mainly of policy issues, is the United Nations Environment Program (UNEP).

In view of the rapidly changing global environment, a new international program has recently been established to look at the issues of global change across a wide range of disciplines. This is known as the International Geosphere-Biosphere Program (IGBP). The International Council of Scientific Unions (ICSU) is the overall governing body for both the International Geosphere-Biosphere Program and the International Association for Meteorology and Atmospheric Physics.

Embedded in these various organisations are a range of specific programs in which many of the Division scientists are active. They include the World Climate Research Program (WCRP), the WMO Committee on Atmospheric Science (CAS), the International Global Atmospheric Chemistry Program (IGAC) and the International Cloud Climatology Program (ICCP).

Another international activity concerns the study of chlorofluorocarbons and other trace gases in the global atmosphere through a program formally known as the Atmospheric Lifetime Experiment (ALE) now operating under the name of the Global Atmospheric Gases Experiment (GAGE).

A very recent international activity towards which the Division is contributing strongly via a number of working groups is the International Government Panel on Climate Change (IPCC). IPCC was set up specifically to provide a world-wide forum for assessment of research, impacts and response strategies with respect to the greenhouse effect.

Affiliations

The committees, panels and editorial boards on which staff members served are listed below. They indicate recognition of the high national and international standing of the Division.

ABBS, Debbie
Honorary Secretary, Australian Meteorological and Oceanographic Society (AMOS)

AYERS, Greg
Associate Editor, *Australian Meteorological Magazine*
Associate Editor, *Clean Air*
Cape Grim Baseline Air Pollution Station (CGBAPS) Working Group

BAINES, Peter
Associate Editor, *Australian Meteorological Magazine*
Editorial Board, *Dynamics of Atmospheres and Oceans*
International Commission for Dynamic Meteorology
International Commission for Dynamical Meteorology, Working Group C (Mesoscale Dynamics)

President, Australian Meteorological and Oceanographic Society (AMOS)

BARTON, Ian
Australian Representative, Committee of Earth Observation Satellites (CEOS) Working Group on Calibration and Validation
Science Team Member, Along Track Scanning Radiometer for ERS-1, ESA

BEER, Tom
Convenor, Awards Sub-Committee, AMOS
Editorial Board, *Australian Maritime Atlas*
Executive Committee of Simulation Society of Australia

BIGG, Keith
CGBAPS Working Group

BIRD, Ian
Advisory Committee, Department of Science
Adviser, Divisional Engineering, CSIRO Institute of Physical Sciences
Convenor, CSIRO Electronics Seminars Committee, Victoria
National Committee for Antarctic Research, Australian Academy of Science
Programme Assessor, Engineering, Antarctic Research Policy

BOUMA, Willem
CGBAPS Working Group
Secretary, Division of Atmospheric Research Advisory Committee

FRANCEY, Roger
CGBAPS Working Group

FRASER, Paul
CGBAPS Working Group
Clean Air Society of Australia and New Zealand
Co-Editor, *Baseline 1985*, *Baseline1986*
CSIRO Representative at meetings of the Global Atmospheric Gases Experiment (GAGE)
CSIRO Scientific Adviser to Aerosol Association of Australia
Invited Australian Representative at the 8th meeting of the United Nations Environment Program's Co-ordinating Committee on the Ozone Layer
Invited Chairman, Trace Gas Trends Group, NASA Ozone Trends Panel
National Health and Medical Research Council Committee on Chlorofluorocarbons and Alternative Aerosol Propellants

FREDERIKSEN, Jorgen
Sub-Editor, *Quarterly Journal of the Royal Meteorological Society*

GALBALLY, Ian
Associate Editor, *Journal of Atmospheric Chemistry*
CGBAPS Working Group
Commission on Atmospheric Chemistry and Global Pollution of IAMAP
Editorial Board, *Tellus*
International Ozone Commission of IAMAP
Latrobe Valley Airshed Study Working Group on Ozone
Scientific Advisory Committee of SCOPE Biospheric Trace Gas Emissions Project

GARRATT, John
Chairman, World Meteorological Organization's (WMO) Group of Rapporteurs on Boundary-Layer Problems
Editorial Board, *Boundary-Layer Meteorology*
Editorial Committee, *Quarterly Journal of Royal Meteorology Society*
WMO Working Group on Boundary-Layer Problems

GRAS, John
CGBAPS Working Group

HUNT, Barrie
Associate Editor, *Climate Dynamics*
Australian World Climate Research Program Committee
Scientific Discipline Member, Scientific Committee for Solar Terrestrial Physics

LONG, Alex
Associate Editor, *Journal of Climate and Applied Meteorology*

MANINS, Peter
Project Director, LVASS Working Group

PALTRIDGE, Garth
Chairman, National Committee for Atmospheric Science
International Radiation Commission

PEARMAN, Graeme
Australian Academy of Science, National Committee of Atmospheric Sciences
Australian Academy of Science, National Committee for the International Geosphere-Biosphere Program
CGBAPS Working Group
IAMAP Commission on Atmospheric Chemistry and Global Pollution
International Council of Scientific Unions and the WMO Joint Organizing Committee Working Group on Data for Climate Research
WMO Commission for Instruments and Methods for Environmental Pollution Measurement
WMO Working Group on Atmospheric Carbon Dioxide

PITTOCK, Barrie
Australian delegate to SCOPE General Assembly in 1985
SCOPE Standing Committee on Publications
Chairperson, Australian Academy of Science's National Committee for the Environment
Editorial Board, *Climate Change*, *Journal of Climatology* and *Natural Hazards Journal*
SCOPE Working Group on the Environmental Consequences of Nuclear War

PLATT, Martin
Chairman, Australasian Physics of Remote Sensing Group
International Committee for Laser Atmospheric Studies
CGBAPS Working Group
International Radiation Commission, IAMAP

PLUMB, Alan
Associate Editor, *Journal of the Atmospheric Sciences*
Chairman, WMO/NASA Ozone Assessment Working Group
Editorial Committee, *Pure and Applied Geophysics*
International Commission for Dynamical Meteorology

PRATA, Fred
Co-Chairman, Volcanic Ash Detection and Air Safety Working Group, COSSA
Science Team Member, Along Track Scanning Radiometer for ERS-1, ESA

RYAN, Brian
Aircraft Advisory Committee, COSSA

SAWFORD, Brian
Leader, Non Reactive Gases Project Team of the LVASS

TUCKER, Brian
Australian Environment Council Steering Committee
Australian Ionizing Radiation Advisory Committee
Cape Grim Management Committee
Chairman, Latrobe Valley Airshed Study Steering Committee
Executive Committee of Scientific Committee on Oceanic Research, SCOR
National Bushfire Research Unit Steering Committee
President, International Association of Meteorology and Atmospheric Physics, IAMAP

TURNER, Peter
Chisholm Institute of Technology Course Committee for the Graduate Diploma in Computer Graphics
Victorian Remote Sensing Committee

Lecture courses and affiliations with Australian universities

A number of Division staff have presented lecture courses at universities:

BEER, Tom – Melbourne 1987. Lectures on "Introductory Physical Oceanography" to second year meteorology students.

FRASER, Paul – Wollongong 1985, 1986 and 1987. Lecture course on "Atmospheric Chemistry" to third year chemistry students.

GALBALLY, Ian – Melbourne 1985 and 1986. Lectures on "The Composition and Chemistry of the Atmosphere" to fourth year meteorology students.

HUGHES, Roger – Monash 1987. Half course on "Physical Oceanography". Melbourne 1988. Lecture course on "Mathematics in Industry".

PITTOCK, Barrie – Melbourne 1985 and 1986. Lectures on "Climate Change and Variability" to second year meteorology students.

Transfers and Retirements

Dr Keith Bigg, a Senior Principal Research Scientist, **Dr Chris Coulman**, former Officer-in-Charge of the Cloud Physics Laboratory in Sydney and **Peter Hyson**, a Senior Experimental Scientist retired during the period covered by this report. **Eric Webb** has also retired but will stay with the Division as an Honorary Research Fellow.

Dr Alan Plumb has accepted a Chair at Massechusetts Institute of Technology in Boston. **Dr Warren King** has moved to the CSIRO Division of Radiophysics in Sydney and **Dr Peter Howells** is now employed by the company "Applied Financial".

A number of scientists have completed term positions at the Division – **Steven Banks, Frank Di Marzio, Harry Hendon, Richard Kleeman, Dianna Davies, John Everett, Julie Golds, Denis McConalogue** and **Lou Ripari.**

Support staff who have left the Division include **Wayne Knight, Ray Meyer, John Swannie** and **Neil Tyson.**

A number of staff have moved from the old CSIRO Division of Cloud Physics in Sydney during the reporting period – **Tony Adriaansen, Lynne Hanrahan, Enid Turton, Anthony Whichello, Laurie Carmichael** and **Barbara Georgeson.**

Publications

ABBS, D.J. (1986). Sea-breeze interactions along a concave coastline in Southern Australia: observations and numerical modeling study. *Mon. Weather Rev.*, **114**: 831-848.

ABBS, D.J. and R.A. PIELKE (1986). Thermally forced surface flow and convergence patterns over Northeast Colorado. *Mon. Weather Rev.*, **114**: 2281-2296.

ABBS, D.J. and R.A. PIELKE (1987). Numerical simulations of orographic effects on NE Colorado snowstorms. *Meteorol. Atmos. Phys.*, **37**: 1-10.

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AYERS, G.P., R.W. GILLETT and E.R. CAESER (1985). Solubility of ammonia in water in the presence of atmospheric CO_2. *Tellus* **37B**, 35-40.

AYERS, G.P., R.W. GILLETT and U. CERNOT (1986). Chemical composition of rainwater at New Plymouth, N.Z., in 1981-82. *Clean Air.* **20**: 89-93.

AYERS, G.P., J.P. IVEY and H.S. GOODMAN (1986). Sulfate and methanesulfonate in the maritime aerosol at Cape Grim, Tasmania. *J. Atmos. Chem.* **4**: 173-185.

AYERS, G.P., J.P. IVEY and H.S. GOODMAN. (1986). Seasonal cycle in methanesulfonate in the aerosol at Cape Grim. In: *Baseline 83-84* (Eds R.J. Francey and B.W. Forgan). Bureau of Meteorology/CSIRO Division of Atmospheric Research, Australia, 1986. pp.15-17.

IVEY, J.P., D.M. DAVIES, V. MORGAN and G.P. AYERS (1986). Methanesulfonate in Antarctic ice. *Tellus*, **38B**: 375-379.

AYERS, G.P., R.W. GILLETT and U. CERNOT (1987). Rainwater acidity in Sydney, an addendum. *Clean Air* **21**, 68-69.

AYERS, G.P. and R.W. GILLETT (1988). Acidification in Australia. In: *Scope 36, Acidification in Tropical Countries*, Ed. H. Rodhe and R. Herrera, Wiley and Sons, pp.347-402.

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GRIMSHAW, R.H.J., P.G. BAINES and R.C. BELL (1985). The reflection and diffraction of internal waves from the junction of a slit and a half-space. *Dyn. Atmos. Oceans.* **9**, 85-120.

BAINES, P.G. and K.P. HOINKA (1985). Stratified flow over two-dimensional topography in fluid of infinite depth: a laboratory simulation. *J. Atmos. Sci.*, **42**: 1614-1630.

BAINES, P.G. (1986). Internal tides, internal waves, and near-inertial motions. In: *Baroclinic Processes on Continental Shelves, Coastal and Estuarine Sciences* 3, American Geophysical Union, 19-31.

BAINES, P.G. (1986). The hydraulics of stratified flow over topography. *9th Aust. Fluid Mechanics Conference*, Auckland, N.Z., 436-439.

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BAINES, P.G. (1987). The effects of rotation on disturbances upstream of cold fronts approaching south-eastern Australia. *2nd International Conference on Southern Hemisphere Meteorology*, Dec. 1-5, 1986, Wellington, N.Z.

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BAINES, P.G. (1988). Meteorology and physical oceanography in Australia. In: *Priorities in research, operations and education.* Ed.Peter G. Baines. *Report of a discussion meeting organised by the Australian Branch of the Royal Meteorological Society*, July 1987.

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Conference presentations

Second Australian Conference on Tropical Meteorology, Perth, 11-12 July 1985
HENDON, H. - Linear and nonlinear response to tropical diabatic heating
PRATA, A.J. and M.J. LYNCH - Satellite radiance measurements of tropical cyclones

ANZAAS, Melbourne, August 1985
AYERS, G.P.- Acid rain : the Australian context

Fourth Australian Laser Conference, Macquarie University, August 1985
PLATT, C.M.R. and J.C. SCOTT - The application of high-power pulsed lasers in meteorology and climatology

IAMAP/IAPSO Joint Assembly, Honolulu, 5-16 August 1985
FREDERIKSEN, J.S. and WEBSTER, P.J. - Alternative theories of atmospheric teleconnections and low-frequency fluctuations
PITTOCK, A.B. - Climatic effects of nuclear war: an overview

Fourth WMO Scientific Conference on Weather Modification, Honolulu, 12-14 August, 1985
LONG, A.B. et al. - Joint remote-sensing, radar, and surface microphysical investigations of winter orographic clouds in central Utah, USA

Second Workshop on Wind Engineering and Industrial Aerodynamics, Highett, 28-30 August 1985
MANINS, P.C. - The wind in a broad valley - the Latrobe Valley of Victoria
SAWFORD, B.L. - Plume concentration statistics in the atmospheric boundary layer

CACGP Conference on Atmospheric Carbon Dioxide, Kandersteg, Switzerland, 2-6 September, 1985
ENTING, I.G. - The application of lattice statistics to bubble trapping in ice

Workshop on Atmospheric Transport Processes and Plant Canopies, Canberra, 4-6 September 1985
WEBB, E.K. - the B-B combination method

International Conference on Acidic Precipitation, Muskoka, Canada, 15-20 September 1985
GALBALLY, I.E. - Dry deposition of NO_2 and HNO_3 and emission of NO - How much do we know?

Bureau of Reclamation Workshop on the Physics of Winter Orographic Precipitation and its Modification, Denver, Colorado, 1-3 October 1985
LONG, A.B. and J. HEIMBACH - Discussions on seeding methods, transport and diffusion of seeding

Drought Research in Australia 1985, Melbourne, 21-22 October 1985
BARTON, I.J. - SAVE - a satellite validation experiment
HUNT, B.G. - Drought research - the modelling approach
PITTOCK, A.B. - Teleconnection patterns, can they be used for drought forecasting?

Annual Meeting of the Australian Baseline Monitoring Program, Aspendale, November 1985
FRASER, P., N. DEREK, R. O'BRIEN, R. SHEPHERD, R. RASMUSSEN, A. CRAWFORD and L. STEELE - Intercomparison of halocarbon and nitrous oxide measurements, 1976-1984

Seventh Symposium on Turbulence and Diffusion, Boulder, Colorado 12-15 November 1985
SAWFORD, B.L. - Concentration statistics for surface plumes in the atmospheric boundary layer

Fall Meeting of the American Geophysical Union, San Francisco, California, December 1985
STEELE, L., P. FRASER, R. RASMUSSEN, M. KHALIL, A. CRAWFORD, T. CONWAY, R. GAMMON, K. MASARIE and K. THONING - The global distribution of methane in the troposphere
STEELE, L., T. CONWAY, L. WATERMAN, R. GAMMON, P. FRASER, R. WEISS and R. RASMUSSEN - Measurements of atmospheric methane from the Akademik Korolev cruise, October-December 1983

Air-Sea Interaction and its Consequences Conference, Sydney, 2-5 February 1986
BAINES, P.G. and G.D. HUBBERT - The Bass Strait flux experiment
BARTON, I.J. - How accurately can satellites measure sea surface temperature?
WEBB, E.K. - Free convection theory and the air-sea bulk transfer relationship

First Australasian Workshop on Climatology, University of Newcastle, 13-14 February 1986
PITTOCK, A.B. - Anticipating future climates

Eighth Session of the Co-ordinating Committee on the Ozone layer (CCOL), Nairobi, Kenya, March 1986
FRASER, P. - Recent research results on on-going research activities relevant to the World Plan of Action on the Ozone Layer: Australia

SCOPE Workshop on Tropical Acidification, Caracas, Venezuela, 6-11 April 1986
AYERS, G.P. - Acidification in Australia
GALBALLY, I.E. and R.W. GILLETT - Processes regulating nitrogen compounds in the tropical atmosphere

Second AVHRR Users Meeting, Rutherford Appleton Lab., Oxford, U.K., April 1986
BARTON, I.J. - AVHRR measurements of land surface emissivity

Tenth Conference on Weather Modification, Arlington, Virginia, 27-30 May 1986
LONG, A.B. - Mesoscale air motions and supercooled liquid water development in winter clouds in a mountainous region

Conference on Science in the National Parks, Fort Collins, Colorado, July 1986
PEILKE, R.A., R.W. ARRITT, R.T. MCNIDER, M. SEGAL, C.H. YU and W.L. PHYSICK - Screening estimates of maximum 24-hour average pollution concentrations on mountain valleys during synoptic stagnation

Royal Australian Chemical Institute/Federation of Asian Chemical Societies Meeting on Environmental Chemistry, Darwin, Australia, 7-11 July 1986
GALBALLY, I.E. - Nitrogen cycling in the tropical atmosphere

WMO/IUGG Numerical Weather Prediction Symposium, Tokyo, 4-8 August 1986
McGREGOR, J.L. - Accuracy and initialization of a two-time level semi-Lagrangian model

Third International TOVS Study Conference, Wisconsin, U.S.A., 13-19 August 1986
PRATA, A.J., M.J. LYNCH, R. HILLE and L. VAN BURGEL - Observations of tropical cyclones in Western Australia using combined TOVS and AVHRR radiances

Seventh World Clean Air Congress, Sydney, August 1986
FRASER, P. - Carbon monoxide in the Southern Hemisphere

IGARSS Symposium, Zurich, Switzerland, September 1986
LLEWELLYN-JONES, D.T., I.J. BARTON, J. DELDERFIELD, I.M. MASON, D.R. PICK and E.J. WILLIAMSON - The along track scanning radiometer for ERS-1: Performance, calibration and validation

Conference on Cloud Physics, Snowmass, Colorado, 22-26 September 1986
LONG, A.B. et al. - Remote sensing investigation of the mesoscale kinematics and the microphysics of a winter mountain storm

Seventh Australian Institute of Physics Congress, Workshop on solar-terrestrial and space physics, Adelaide, 25-29 September 1986
HUNT, B.G. - General circulation modelling of the middle atmosphere

First Australian AVHRR Conference, Perth, Western Australia, 22-24 October 1986
BARBER, J. and G.W. PALTRIDGE - Fuel moisture content of vegetation from AVHRR - an operational fire potential monitoring system
PRATA, A.J., A.F. PEARCE, J.B. WELLS and J. CARRIER - Satellite sea surface temperature measurements of the Leeuwin current
M.J. LYNCH, A.J. PRATA and J.R. HUNT - Sea surface temperature anomalies off the North West shelf of Western Australia
WELLS J.B. and A.J. PRATA - Processing NOAA data on microcomputers
HILLE R., L. VAN BURGEL, M.J. LYNCH and A.J. PRATA - Applications of NOAA satellite data to the study of tropical cyclones
HICK P.T., A.J. PRATA and N.A. CAMPBELL - NOAA-AVHRR satellite evaluation of the areal extent of bushfire damage in Western Australia
TURNER, P.J. et al. - The Arlunya Image Processing Workstation

Civil Defence Symposium, Natural Disasters Organisation, Victoria, Australia. 22-24 October 1986
GALBALLY, I.E. - Climatology and civil defence in Australia.

Scientific Applications of Baseline Observations of Atmospheric Composition, Aspendale, November 1986
AYERS, G.P. - Sulfate and methanesulfonate in the maritime aerosol at Cape Grim, Tasmania

National Forum on Science and Technology, Canberra, 6-7 November 1986
PITTOCK, A.B. - The economic importance of environmental research

Australia and New Zealand Solar Energy Society Conference, Adelaide, 12-14 November 1986
AKBARZADE, A and P.C.MANINS - Side wall effects in the operation of solar ponds

Latrobe Valley Air Shed Study modellers workshop, Melbourne, 18 November 1986
ABBS, D.J. - Comparative experiments between two prognostic models under summertime conditions in the Latrobe Valley. Part I - the CSU mesoscale model
McGREGOR, J.L. - Comparative experiments between two prognostic models. Part II - the MRI local winds model
PHYSICK, W.L. - Why the Latrobe Valley is interesting meteorologically

SCOR Symposium - Interfaces in the Ocean, Hobart, 24-26 November 1986.
WEBB, E.K. - Prospects for measurement of air-sea CO_2 transfer

AMS Southern Hemisphere Meteorology Conference, Wellington, New Zealand, 1-5 December 1986
GARRATT, J.R. - Numerical study of atmospheric gravity currents, with reference to Australian summertime cold fronts
HENDON, H. - On the structure and dynamics of the troposphere over the Australian Tropical Region
HOWELLS, P.A.C. - A numerical study of the 1 December 1982 Southerly Buster Event

Ninth Australasian Fluid Mechanics Conference, Auckland, 8-12 December 1986
FREDERIKSEN, J.S. and C.S. FREDERIKSEN - The roles of baroclinic and membarotropic instability during cyclogenesis and atmospheric blocking
SAWFORD, B.L. and F.M. GUEST - Lagrangian statistical simulation of turbulent dispersion in the convective boundary layer

Conference on Mechanisms of Interannual and Longer Term Climatic Variations, Melbourne, 8-12 December 1986
FREDERIKSEN, J.S. - Instability theory of atmospheric fluctuations
GORDON, H.B. - Interannual climatic fluctuations attributable to nonlinearities
HUGHES, R.L. - The hydraulic switch for western boundary heat flux
HUNT, B.G. - Nonlinear influences in climatic perturbations
HUNT, B.G. - The influence of an ozone hole on climate - experiments with a general circulation model
PALTRIDGE, G.W. - Cloud-radiative interactions and infrared absorbers

PITTOCK, A.B. - Sensitivity studies on nuclear winter effects with implications for changed climates
PLUMB, R.A. - Instabilities of simple coupled atmosphere-ocean models

Workshop on low-level flow around bushfires - study and measurement, Canberra, 17 December 1986
GARRATT, J.R. - Winds in the lower atmosphere: A Review
PHYSICK, W.L. - Numerical modelling of low-level winds and its practical application

ANZAAS Congress, Palmerston North, NZ, 26-30 January 1987
PITTOCK, A.B. - Atmospheric and climatic consequences of nuclear war

SCOPE-ENUWAR Workshop, Bangkok, Thailand, 9-12 February 1987
PITTOCK, A.B. - Sensitivity studies on nuclear winter effects in the southern hemisphere with wider implications

GMCC Annual Meeting, Boulder, Colorado, March 1987
AYERS, G.P. - Measurement programs at the Cape Grim Baseline Station

Eighth Symposium on Turbulence and Diffusion, San Diego, California, April 1987
GARRATT, J.R. - Interaction between the planetary boundary layer and an evolving atmospheric gravity current
SAWFORD, B.L. and F.M. GUEST - Uniqueness and universality of Lagrangian stochastic models of turbulent dispersion

American Chemical Society Symposium on Atmospheric Methane, Denver, Colorado, April 1987
FRASER, P.J. - Global methane: a Southern Hemisphere perspective

Australian Institute for Refrigeration, Air Conditioning and Heating Workshop, Parkville, Victoria, April 1987
FRASER, P.J. - Chlorofluorocarbons, stratospheric ozone and the refrigeration industry

Mesoscale Topographic Effects in the Australian Region, Aspendale, 1 May 1987
BAINES, P. - Stratified flow past 3-D barriers
McGREGOR, J.L. - Alternative mechanisms for the Melbourne eddy
PHYSICK, W. and D.J. ABBS - Latrobe Valley flows

Bushfires in Heath Conference, Canberra, 4-6 May 1987
BEER, T. - Bushfire Physics

Simulation Society of Australia Biennial Conference, Melbourne, 11-13 May 1987
BEER, T. - Modelling the physical environment
FREDERIKSEN, C.S. and J.S. FREDERIKSEN - Simulation and models of the role of topographic instability in the formation of atmospheric teleconnection patterns

Australian Conference on Lasers and Spectroscopy, Surfers Paradise, 11-15 May 1987
BANK, S.M., C.M.R. PLATT, D.J. BOOTH and G.R. PATTERSON - Lidar remote sensing at CSIRO Division of Atmospheric Research
BOOTH, D.J., S.M. BANKS, J. GRAS and C.M.R. PLATT - Lidar measurement of aerosol backscatter and comparison with Mie calculations using measured aerosol profiles

NERDDC Workshop on the Scientific Basis of Standards for the Release of Energy Based Air Pollutants in Australia, Canberra, 19-20 May 1987
MANINS, P.C. - Assimilative capacity of the Latrobe Valley airshed for emissions from energy-related industrial activity
CARRAS, J., G. ROSS, B.L. SAWFORD and R. SIMPSON - Methods of source-receptor modelling for air quality applications

Workshop on forecasting implications of the Cold Fronts Research Programme, Melbourne, 2-3 June 1987
PHYSICK, W.L. - Type 1 and Type 2 fronts
PHYSICK, W.L. - What do surface observations mean?
PHYSICK, W.L. - Topographic effects
RYAN, B.F. - Prognosis of line features

Clean Air Society of Australia and New Zealand, Queensland Branch Annual Meeting, Brisbane, June 1987
FRASER. P.J. - Ozone in the upper atmosphere

Meeting on Priorities in Research, Operations and Education in Meteorology and Physical Oceanography in Australia, Melbourne, 2-3 July 1987
PITTOCK, A.B. - Priorities in climatic research

Institute of Foresters Conference, "Tasmania's Forests - Beyond 2000", Tasmania 4 July 1987
PITTOCK, A.B. - Forests Beyond 2000 - effects of atmospheric change.

Workshop on Cumulus Parameterization, Melbourne, 22 July 1987
McGREGOR, J.L. - The BMRC spectral model: choice of parameterization scheme

Coherent Laser Radar: Technology and Applications, Aspen, Colorado, July 27-30, 1987
GRAS, J.L. - Australian free atmospheric-aerosol measurements

IUGG General Assembly, Special Session on Global Tropospheric Chemistry, Vancouver, Canada, 9-22 August 1987
GALBALLY, I.E. - Nitrogen chemistry in the atmosphere

IUGG General Assembly, Vancouver 12-18 August, 1987
BAINES, P.G. and G.D. HUBBERT - The Bass Strait Flux Experiment - fluid transports and causes
BAINES, P.G. - Topographic effects in the atmosphere - a review
PITTOCK, A.B. - Climatic effects of smoke and dust produced from nuclear conflagrations

Symposium on Mesoscale Analysis and Forecasting, Vancouver, Canada, 17-19 August 1987
WILSON, K.J. and B.F. RYAN - The role of low-level cooling in a conceptual model of the Australian summer time cool change: implications for very-short-range forecasting

Third Conference on Mesoscale Processes, Vancouver, Canada, 21-26 August 1987
RYAN, B.F., G.R. TRIPOLI and W.R. COTTON - Upside-down convection Down Under: A numerical study

InternationaL Conference On Computational Techniques And Applications, Sydney, 24-27 August 1987
FREDERIKSEN, J.S. and R.C. BELL - Simulations and closure theory for interacting barotropic waves
FREDERIKSEN, C.S. and J.S. FREDERIKSEN - The application of spectral techniques in a study of the stability of orographically forced planetary waves
KLEEMAN, R., J.S. FREDERIKSEN and R.C. BELL - Statistical dynamics of quasi-geostrophic flows

International Geographical Union Study Group on Recent Climatic Change, Sheffield, UK, 24-28 August 1987
PITTOCK, A.B. - Climatic effects of nuclear war: a perspective from the Southern Hemisphere
PITTOCK, A.B. - Towards estimates of the practical consequences of the greenhouse effect

CACGP Symposium on Tropospheric Chemistry, Peterborough, Canada, August 1987
FRASER, P.J. - The CSIRO global methane program

International Symposium on Flow and Transport in the Natural Environment, Canberra, 31 August- 4 September 1987
MANINS, P.C. - Wind blocking in periodic valleys

International Satellite Land Surface Climatology Project, Yalta, USSR, September 1987
HUNT, B.G. - Surface hydrology impact in a general circulation model

Eleventh Conference on Weather Modification, Edmonton, Alberta, 6-8 October 1987
LONG, A.B. - On the precipitation efficiency of a winter mountain storm in Utah

IAF Congress, Brighton, U.K., October 1987
BARTON, I.J., - Future Australian participation in meteorology from space

NASA Ozone Trends Panel Meeting, Les Raisses Ste-Croix, Switzerland, November 1987
FRASER, P.J. - Trends in source gases

Greenhouse 87 Conference, Melbourne, 30 November - 4 December 1987
BEER, T., A.M. GILL and P.H.R. MOORE. - Australian bushfire danger under changing climatic regimes
PEARMAN, G.I. - Greenhouse gases: evidence for atmospheric changes and anthropogenic causes
PITTOCK, A.B. - Actual and anticipated changes in Australia's climate
TUCKER, G.B. - Climate modelling: how does it work?

Latrobe Valley Air Shed Study Modelling Seminar, 4 December 1987
McGREGOR, J.L. - In search of the Gabo Island eddy

Australian Applied Mathematics Conference, Leura, 7-11 February, 1988
BEER, T. - Optimising performance of bushfire spread models
ENTING, I.G. and G.N. NEWSAM - Inverse problems in atmospheric constituent studies

Second Conference on Air-Sea Interaction, Merimbula, NSW, 14-17 February 1988
BAINES, P.G. and G.D. HUBBERT - Fluid transport through Bass Strait
BARTON, I.J. and J.D. PENROSE - Experimental investigations of bulk/skin temperature differences in the open ocean
HUGHES, R.L. - An aspect of coastal current separation
HUNT, B.G. - Some oceanic problems in climatic research
WALSH, K. and A.B. PITTOCK - The sensitivity of a coupled atmospheric-oceanic model to variations in the albedo and absorptivity of a stratospheric aerosol layer

Conference on Global Change, Australian Academy of Science, 24-27 February 1988
GALBALLY, I.E. - The biosphere, atmospheric composition and climate
HUNT, B.G. - Perturbations to general atmospheric circulation caused by global change
PEARMAN, G.I. - The greenhouse effect
PITTOCK, A.B. - Changes in climatic variability
TUCKER, G.B. - Global geosphere-biosphere modelling

Global Change Conference, Canberra, February 1988
PITTOCK, A.B. - Regional climatic change and its impacts

WMO Meeting on Time Series analysis of CO2 data, Hilo, Hawaii, March 1988
ENTING, I.G. - CO_2 measurements of CSIRO (Australia)
ENTING, I.G. - Studies of baseline selection criteria for Cape Grim
ENTING, I.G. - Some comments on Kalman filtering of CO_2 data
ENTING, I.G. - Time series studies of CO_2 data in Division of Atmospheric Research
ENTING, I.G. and M. MANNING. - The seasonal cycle of CO_2 at Mauna Loa: A re-analysis of a digital filtering study

Propel Media Symposium, Sydney, March 1988
FRASER, P.J. - NASA Ozone Trends Panel Report

Aerosol Association of Australia Media Seminar, Sydney, April 1988
FRASER, P.J. - NASA Ozone Trends Panel Report

Annual Meeting Science Teachers Association of NSW, Sydney, April 1988
FRASER, P.J. - The Antarctic Ozone Hole

Annual Meeting Science Teachers Association of Victoria, Monash University, April 1988
FRASER, P.J. - Antarctic Ozone

Centenary ANZAAS Conference, Sydney, May 1988
BARTON, I.J. - Remote sensing from ERS-1
FRASER. P.J. - Depletion of stratospheric ozone

Spectral Modelling Workshop, Melbourne University, 24 May 1988
McGREGOR, J.L. - Implementation of the boundary layer and cumulus parameterization schemes in the BMRC spectral model

Symposium on Greenhouse Effect and Ozone Depletion, Bussleton, WA, May 1988.
FRASER, P.J. - NASA Ozone Trends Panel Report.

Latrobe Valley Airshed Study End-of-Study Symposium, Melbourne, 20-21 June 1988

AYERS, G.P. - The Latrobe Valley Aerosol/Visibility Study
MCGREGOR, J.L. and D.J. ABBS - Modelling mesoscale effects in the Latrobe Valley with a nested model
MANINS, P.C. - Meteorology and air quality of the Latrobe Valley
SAWFORD, B.L. - Primary air pollution in the Latrobe Valley

Air Quality Modelling - Science and Application. NERD&D Program Workshop, Melbourne, 23-24 June 1988

BAINES, P.G. - Laboratory simulation of topographic effects on atmospheric flows in stable conditions
BORGAS, M.S. - Recent modelling developments in turbulent dispersion problems
MANINS, P.C. - Model performance in the Latrobe Valley Airshed Study
PHYSICK, W.L. - Mesoscale meteorological and Lagrangian dispersion models : a numerical system for predicting air quality

National Fisheries Forum and Exhibition 88, Brisbane, 28-30 June 1988

BOUMA, W.J. - El Nino, the greenhouse effect and the Antarctic ozone hole: perturbations of the atmospheric/ocean system
RICHARDSON, S.A. - Satellite derived sea-surface temperature imagery

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30 June 1988

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C.M. Elsworth
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M.L. Sparshott
M.B. Swingler
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Personal Secretary
R. Baum

Radio Tradesman
T.W. Carey
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Storeman
P.R. Harris

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G. Broome

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