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Scientific facilities at the CSIRO Division of Atmospheric Research

Aircraft Instrumentation Laboratory

Developing, maintaining and calibrating instruments.

CSIRO Data Acquisition and Telemetry Network (CSIDAT)

Acquiring high quality surface radiation data.

Gas chromatograph - mass spectrometer system

Measuring hydrocarbons and air toxics.

Geophysical Data Processing Facility

Acquiring and processing satellite data.

Geophysical Fluid Dynamics Laboratory

Modelling flow in the atmosphere and the ocean using water tanks.

Global Atmospheric Sampling Laboratory (GASLAB)

Measuring concentrations and the isotopic composition of greenhouse and ozone-depleting gases.

Ice Core Extraction Laboratory (ICELAB)

Assessing past atmospheric composition.

Lidar and radiometers

Remotely measuring properties of clouds, atmospheric particles and smoke plumes.

Numerical models of the atmosphere and climate

Advancing understanding and prediction ability of weather and climate.

Precipitation Chemistry Laboratory

Measuring atmospheric acidity.

Wind tunnel

Studying atmospheric dispersion; calibrating instruments (NATA registered).



The past few years have seen significant changes in the way CSIRO seeks to contribute to the welfare of Australia. In common with trends around the world, there has been greater concern as to the effectiveness with which we use resources which, after all, come primarily from the public purse. One mechanism introduced by Government to encourage a closer match of research activities with community perceptions of research needs has been the setting of targets for external earnings. The clients who contract research from CSIRO will wish a greater say in what that research addresses. An internally imposed mechanism has been CSIRO's priorities setting process, linked to an annual re-distribution of 1.5% of the appropriation budget to target new initiatives in the high priority areas.

All staff of the Division of Atmospheric Research have responded to these changes, modifying the way they carry out their respective duties, and almost without exception responding to the challenge of change. This might be one of the country's best kept secrets, but I hold them in high regard for this commitment to CSIRO and its developing principles.

This is not to say that we have found all of the answers, rather that one should not underestimate the achievements thus far, nor the challenges of continuous improvement. The users of our research tell us that they respect the scientific and technical excellence of what we do, but they ask us to improve further our responsiveness to their needs and the timeliness of what we report.

There remain important issues to be addressed. These include the sometimes apparent insensitive and/or inappropriate transfer of management/marketing models, themselves transient and often untested, to the conduct of scientific research with a failure to recognise the special needs of the strategic research environment. We need a clear, corporately-held position on the appropriate balance between responsive (client driven) and proactive (science driven) research and other issues of balance such as the selling of products and the creation of intellectual wealth. As CSIRO and the Division move forward, these issues need wide debate and strong leadership. We must ensure that the debate is not curtailed by the apparent attractiveness of simplistic, ideologically driven imperatives. The world is not that simple. Nor is the role that CSIRO should play in the provision of services to the total Australian community. CSIRO must be pluralistic in its mission and that itself requires breadth of vision and often a degree of tolerance. Pluralism for CSIRO should not be the sticking of sectional activities into easily definable but different boxes, but an all-pervasive pluralism, a culture of intertwined objectives and methods for meeting those objectives.

The Division's performance over the past two years has been most impressive.

We have:

- Found several key applications for our expertise in atmospheric pollution, both measurement and modelling.
- Made major progress in developing state-of-the-art climate models.
- Completed setting up GASLAB, a world-class facility for measuring concentrations and the isotopic composition of greenhouse and ozone depleting gases.
- Further developed our strength in process studies of the climate system via application of remote sensing field studies of cloud composition and micro-physics.

Significant new ways in which we have begun to operate include the developing multi-Divisional programs and Co-operative Research Centres. Both mechanisms open up opportunities to combine disciplinary strengths and institutional differences into teams that transcend the capacity of individual components. This is likely to be a permanent feature that will outlast the more transient management experiments.

For the Division, a most significant development has been the improved relations with the Bureau of Meteorology which has become formally involved in the multi-Divisional programs for Climate Change, and Climate Variability and Impacts, and which has an important role jointly with the Division, Monash University, Cray Australia, and the CSIRO Division of Applied Physics in the Co-operative Research Centre for Southern Hemisphere Meteorology.

Throughout this period, we have drawn strength from our many colleagues in numerous national and international institutions, from the members of our Divisional Advisory Committee, our Director and the Institute staff, and from interactions with the users of our research. To these colleagues, customers and friends, we extend our thanks.

I applaud our staff for a job well done during times of significant adjustment, for their professionalism and dedication to scientific and professional excellence and for their personal support for me as I learn with them to work in an ever changing world.



Dr Graeme Pearman

Graeme Pearman
Chief of Division

Introduction

There are three key factors underpinning the Division's role and research activities:

- Australia's weather and climate are unique.
Thus, we need a distinct national approach to the issue.
- The atmosphere has no boundaries; our research has numerous international links.
- Much of our research can be characterised as being in the national interest, for the benefit of all.

MISSION

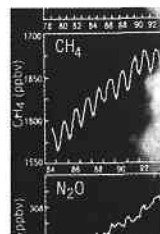
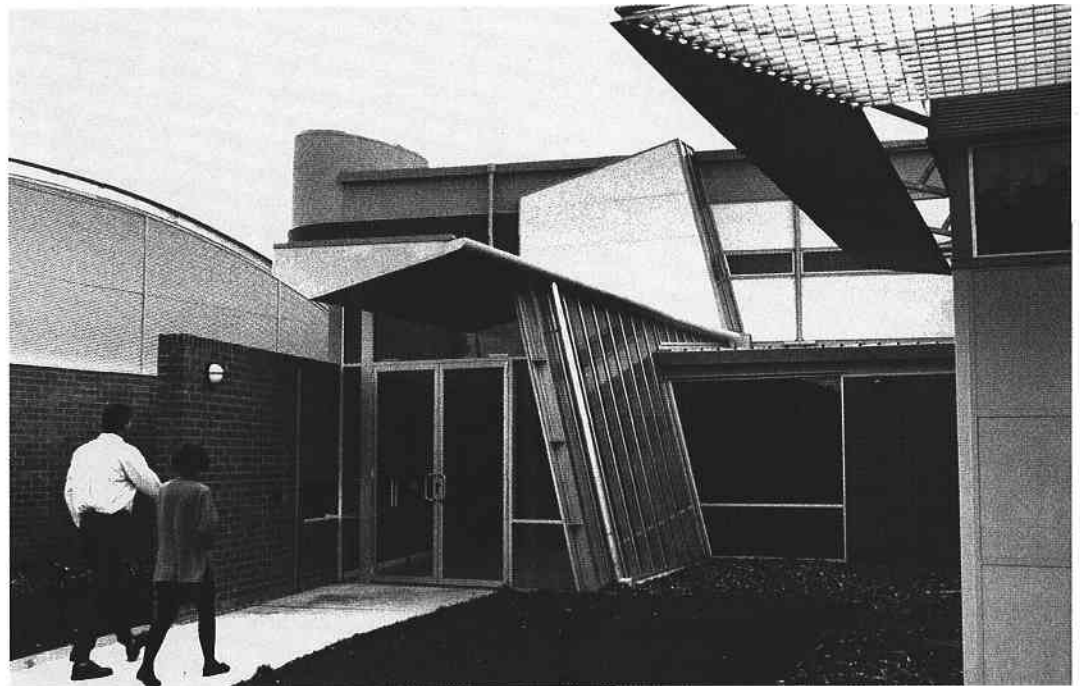
The fundamental objective of our research is to solve significant problems concerning the physics, dynamics and chemistry of the atmosphere over the Australian region, and of the globe insofar as it affects the Australian region, and provide the best possible scientific advice on problems and issues involving the atmosphere.



In the 48-year history of the Division, we have had just three Chiefs. Current Chief, Dr Graeme Pearman (right) shows his predecessors, Dr Brian Tucker (left) and Dr Bill Priestley, through GASLAB.

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Redevelopment of the site was completed early in 1994, providing new laboratory and workshop facilities.



Research activities are performed within four research Programs:

The Atmospheric Pollution Program studies factors that influence urban and regional air quality. The focus is on identifying sources of pollution and the way in which it is formed, transported and dispersed. Activities include theoretical studies of dispersion, laboratory and numerical modelling and field measurements.

The Atmospheric Processes Program aims to improve our knowledge of dynamical systems, rain-bearing storms, the interaction of radiation with clouds and the earth's surface, and of the way in which water vapour affects climate. Scientists within the Program use remote sensing instruments on satellites, planes and on the ground to collect information about the atmosphere, clouds, land surfaces and oceans.

The Climate Modelling Program is developing powerful computer climate models of the global atmosphere and of the combined atmosphere-ocean system. These models are used to investigate climate variability, climate change associated with the enhanced greenhouse effect, and the likely impacts of climate change. A key area of national interest is the development of practical means of forecasting droughts.

Research in the Global Atmospheric Change Program 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. Changes in the chemical composition of the atmosphere are occurring both regionally and globally. At a global level there is now strong evidence that these changes are likely to bring about significant modifications to climate as a result of the greenhouse effect. Research on Australia's contribution to the sources and sinks of greenhouse gases is an additional component of this Program.

Consulting services

The Environmental Consulting and Research Unit (ECRU) coordinates the practical applications of the Division's research. ECRU scientists have successfully completed numerous collaborative and consultancy projects throughout Australia and overseas. The Unit includes specialists in air quality chemistry, pollution dispersion, and meteorology and draws on the skills and expertise of staff from all parts of CSIRO.

Collaboration

The Division contributes to a number of CSIRO's multi-Divisional Programs, designed to tackle scientific challenges facing the country. The Climate Change Research Program studies the causes, mechanisms and likely impacts of the enhanced greenhouse effect; the Climate Variability and Impacts Program investigates extreme events such as droughts and floods and their origins and consequences; and the Air Quality Program is concerned with emissions, transport and impacts of atmospheric pollutants.

Our link with universities has been strengthened by involvement in the Co-operative Research Centre for Southern Hemisphere Meteorology, based at Monash University. The Centre has three research

programs: ozone, global transport modelling, and southern hemisphere climate dynamics.

We have a joint collaborative research plan with the Bureau of Meteorology and are working together on numerous shared activities. The Australian Antarctic Division works collaboratively with us to provide ice cores for studies of past atmospheric composition.

International cooperation within atmospheric science is strong. We participate in major programs, such as the International Geosphere-Biosphere Program, and the World Climate Research Program, and have a range of joint projects with laboratories in many countries.



The Divisional Advisory Committee in 1994: (Standing, from left to right) Dr Doug Gauntlett, Bureau of Meteorology; Dr Garth Paltridge, IASOS; Dr Willem Bouma, Secretary to the Committee; Mr Bob Chynoweth, Parliamentarian; Mr George Littlewood, CRA Limited; Hon. Fred Chaney, University of Western Australia; (Seated) Dr Graeme Pearman, Chief of Division; Dr Brian Robinson, (Advisory Committee Chairman), Victorian EPA; Dr Ian McPhail, SA Department of Education; Ms Gael Jennings, ABC; Dr John Bell, Department of Industry, Science and Technology.

Projects:

Turbulent dispersion

Project Leader: Brian Sawford

Air pollution meteorology

Project Leader: Peter Manins

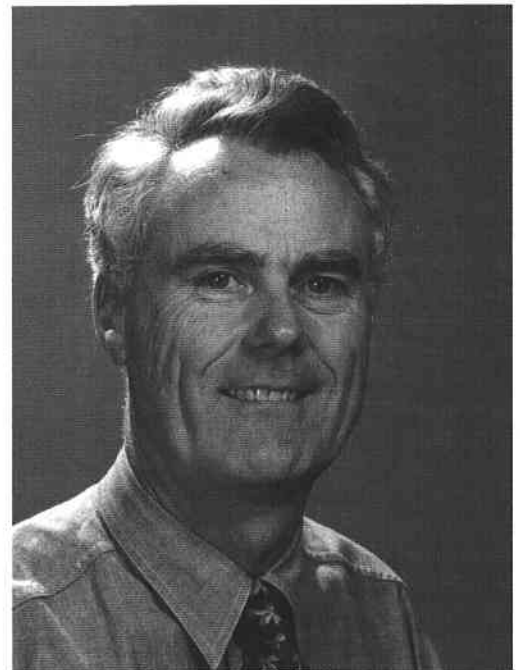
Air quality and visibility

Project Leader: Ian Galbally

The Atmospheric Pollution Program provides solutions to urban and regional air pollution problems. It does this through scientific advances and innovative applications in air pollution meteorology, dispersion and chemistry.

The Program has a strong applied and consulting component. The Environmental Consulting and Research Unit (ECRU) offers direct, relevant, industrial and community applications of the Division's strategic research.

Underpinning developments in our understanding of the dispersion of pollutants are the theoretical studies that seek to better explain pollution transport in the atmosphere. Laboratory experiments allow the theory to be tested in a controlled, easily managed environment. The ultimate test, however, is the real world. Program scientists regularly participate in exhaustive field studies of pollution chemistry and dispersion in cities, and in industrial and power generating regions.



Brian Sawford, Program Leader

The results of our work help planners, industrialists and communities assess the nature and magnitude of existing and likely future air quality problems.

The Atmospheric Pollution Program contributes to the CSIRO-wide Air Quality multi-Divisional Program, which involves strong collaboration between scientists from this Division, the Division of Coal and Energy Technology, the Division of Building, Construction and Engineering and the Centre for Environmental Mechanics.

Dispersion in the atmosphere

Theory

In order to have a rigorous scientific basis for assessing and tackling the problem of air pollution, it is necessary to develop a way of describing the complexity of motion in fluids such as the atmosphere.

The Lagrangian approach to describing the movement of air pollutants is particularly useful as it can be applied to any kind of source and allows for chemical changes. Current theoretical work at the Division focuses on relative dispersion and concentration fluctuations in the atmosphere. These aspects of dispersion are important in improving the treatment of practical problems such as emergency response modelling; and predictions of odour problems, impact of toxic chemicals and chemical reactions.

The Division's wind tunnel has been used for experiments to test the latest theories. In one experiment, a thin heated wire simulated a pollutant source. Air rushing past the wire absorbed heat. Measurements of temperature downwind of the wire represent concentration information – the hotter the air, the higher the simulated concentration.

The temperature data provide statistical information about dispersion including mean pollutant concentrations and variance. We have been able to show that Lagrangian theory is able to satisfactorily describe key elements of concentration statistics measured in this idealised experiment. We are preparing to extend the theory to flows that more closely simulate behaviour of the atmosphere.

The data set obtained from the wind tunnel will be of great use to studies of transient odours, hazards caused by flammable vapours and chemical reactions in plumes.

Laboratory

What happens to a plume after it comes out of a power station chimney? The answer is fairly straightforward if the atmosphere is stable. In this case, the plume's buoyancy – which depends on its temperature – dictates the height that the plume will reach.

However, the situation is far more complex if there is strong convection in the vicinity. The upward motion of air warmed by contact with the ground and the associated downwards

movement of air elsewhere can wreak havoc with attempts to predict plume rise and dispersion. Typically, air pollution models can err by a factor of two or three in estimating plume concentrations.

Over the years, a number of scientists have developed equations for calculating final plume height in convective conditions. As very few data are available to verify these equations, a systematic study of the influence of buoyancy and stack height on plume dispersion was undertaken in the Division's 4000-litre convective boundary-layer tank.

In the tank, convection is simulated by using salty and fresh water to mimic the density difference between hot and cold air. It is these density differences that generate convection.

In the experiments, the plume buoyancy was set by varying the density of coloured saline solution injected through a small model chimney. The chimney was towed through the tank to simulate wind. Each experiment was videotaped for subsequent processing with video frame digitisation techniques.

Results from the laboratory experiments showed that theoretical equations do satisfactorily describe plume rise in convective conditions, provided the inversion layer is well above the maximum height reached by the plume. The equations fail though if the plume top reaches the inversion and is prevented from rising further.

The new data obtained from the experiment will be very valuable for further development of models of plume behaviour under convective conditions.

The Lagrangian Atmospheric Dispersion Model

The Division's Lagrangian Atmospheric Dispersion Model (LADM) accurately simulates the transport and diffusion of emissions for distances of as little as a few hundred metres or as much as a few hundred kilometres.

LADM consists of two main components: a mesoscale wind-field model that predicts the diurnal cycle of winds and turbulence at many levels and grid-points in the atmosphere, and a Lagrangian particle dispersion model that uses the generated winds and turbulence to predict the pathways of pollutants released into the air from any number of locations.

Romy Soriano calibrates an anemometer in the Division's wind tunnel, which is used for studying dispersion in the atmosphere and for testing instruments.

LADM is designed for studies of emissions in different types of terrain, including the coastline, where most of Australia's industry is located. The typical complex wind flows found in coastal regions, such as sea breezes and drainage winds, are well simulated.

Emissions from power stations, refineries, and smelters are all capably handled by LADM. Ground-level pollution problems from elevated sources, such as a typical stack, are often caused by convection. A common example is known as morning fumigation. During the night, air is generally stable so emissions stay at or above stack height. After sunrise the ground begins to warm. Air in contact with the ground begins to rise; elsewhere cooler air drops to replace it. The convective cells set up in this way can draw the plume down to the ground. LADM will accurately determine the impact of this form of fumigation.

Modelling air quality



Another application of LADM is determining worst-case simulations for environmental impact assessment studies.

Recently, LADM has served as the basis for consultancy projects throughout Australia for energy supply and environment protection authorities, as well as for industry. The Environmental Consulting and Research Unit has used LADM for urban airshed studies of Perth, Wollongong-Sydney-Newcastle, and the Tamar Valley.

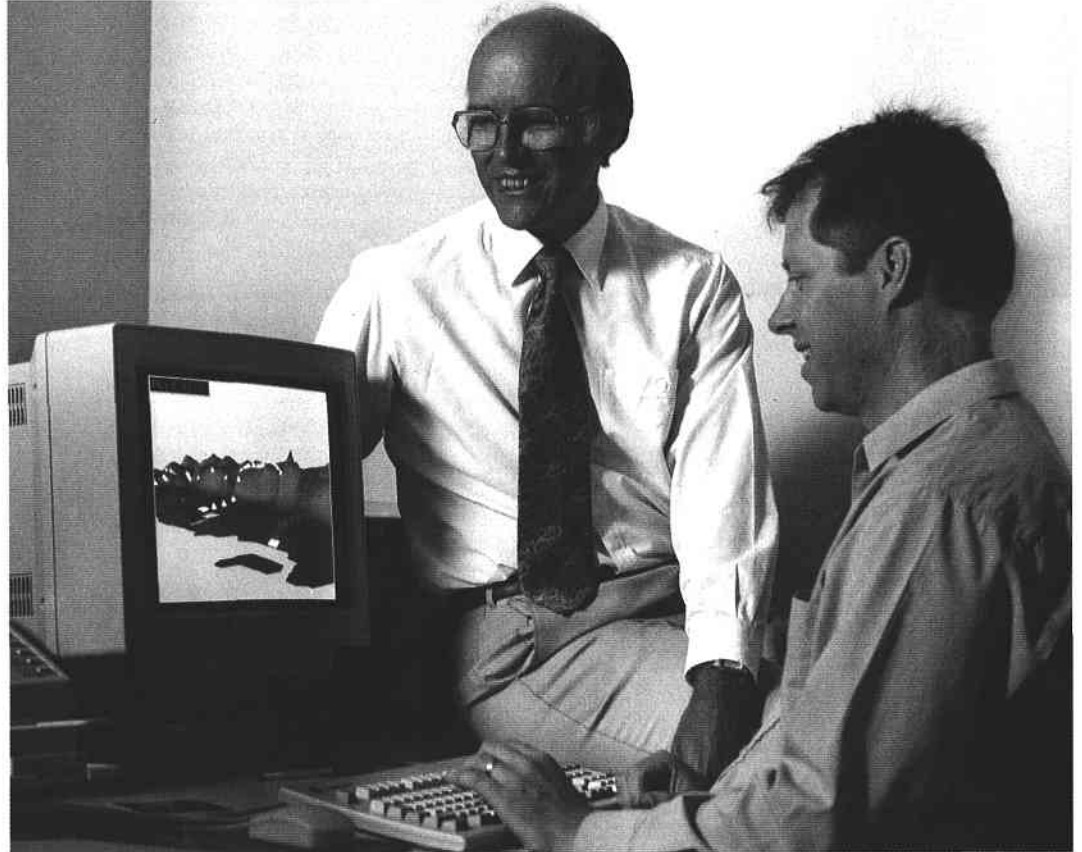
Chemical dispersion models

To fully assess the likely impact of air pollution, knowledge of the chemical composition of the

pollutants is crucial. Chemical reactions in the atmosphere, often driven by sunlight, can transform relatively innocuous substances into harmful compounds.

Chemical dispersion models build upon the concentration information provided by models such as LADM by assessing the likely chemical reactions occurring within an air mass.

The Division is using plume dispersion data from the Hunter Valley in New South Wales to examine how well chemical dispersion models simulate complex smog chemistry in the region. The Environmental Consulting and Research Unit anticipates employing such models for future urban airshed studies.



Peter Manins (left) and Peter Hurley examine air flow over the Perth region simulated by the Lagrangian Atmospheric Dispersion Model.

Air quality in the west

As part of the environmental approval process for a new gas turbine power station at Pinjar, north of Perth, the State Energy Commission of Western Australia and the Department of Environmental Protection are undertaking the Perth Photochemical Smog Study.

The Study comprises an investigation of the formation and distribution of photochemical smog over the Perth region. The Division has been contracted to perform modelling studies and chemical sampling.

Photochemical smog forms on still days when the sun shines on air containing volatile organic compounds and oxides of nitrogen. Volatile organic compounds, such as hydrocarbons, alcohols, aldehydes and ethers, arise mainly from automotive fuels and industrial solvents. The resulting chemical reactions form ozone, which is harmful to humans, animals and plants. Photochemical smog also contains other harmful pollutants such as peroxyacetyl nitrate.

Modelling Perth winds

What are the meteorological conditions that are most likely to favour high ozone levels?

Department of Environmental Protection data from their monitoring station at Caversham, a north-eastern suburb of Perth, showed that most high ozone events happen in summer, often persisting for a number of days. On these occasions, winds are generally from the east or north-east.

Divisional scientists used LADM to predict flow patterns over Perth during days of high ozone. An unexpected outcome from the modelling study is that the sea breeze may not be as fresh and cleansing as Perth residents believe. Emissions from the city's morning peak-hour traffic are often carried out to sea by easterly breezes. Sun shining on the pollutants creates photochemical smog, which may then be caught up in the afternoon sea breeze and carried back over the city.

As well as describing meteorological conditions leading to high ozone levels, the EPA used the modelling work to help determine where air quality monitoring sites should be located.

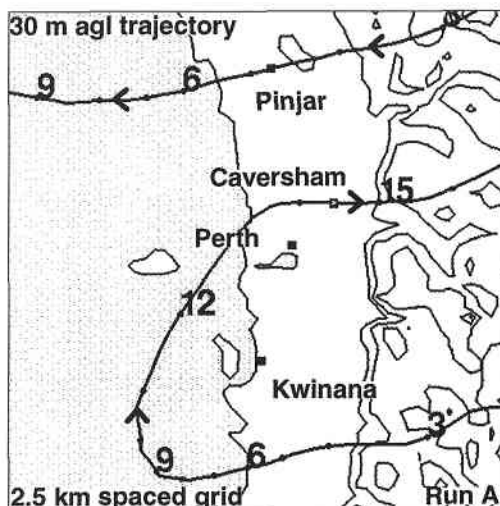
Volatile organic compounds in Perth air

To discover the major sources of volatile organic compounds in Perth's air, Divisional scientists sampled industrial emissions, emissions from vegetation, and vehicle exhaust emissions in the central business district and on freeway and arterial roads. They collected air on smoggy days as well as clear days.

The air samples were collected from a specially equipped car, which enabled measurements to be made from road-side locations, of vehicle emissions and assessments of pollutant levels at a number of specific sites. A portable NO_x analyser helped the scientists track plume locations for measurements of peak pollutant concentrations.

Once the type and amount of volatile organic compounds are known, assessments can be made of the photochemical "age" of smoke plumes and hence their likely source. The Division's sampling regime complemented Cessna 340A aircraft measurements made by the Flinders Institute for Atmospheric and Marine Sciences and the CSIRO Division of Coal and Energy Technology. To confirm the suggestions that pollutants often return to Perth after being blown offshore, air samples were collected from a boat west of the Kwinana industrial area.

In addition to concentrations of volatile organic compounds, the air measurement program yielded data on levels of carbon dioxide, carbon monoxide, methane, oxides of nitrogen and hydrocarbons.



The Division's dispersion modelling has made a major contribution to the Perth Photochemical Smog Study. In this model run, an air parcel travels over land to the sea in the morning, bringing pollutants back across Perth in the early afternoon. The same air parcel heads out to the sea north of Perth the next morning. (The numbers next to the trajectory refer to the time of day, using 24-hour notation.)

The Perth haze study

Concerned with the increasing incidence of haze in metropolitan Perth, the Western Australian Department of Environmental Protection contracted the Division to identify the nature and sources of the problem and to advise on the establishment of a monitoring network.

Haze lowers visibility and is caused by high levels of fine airborne aerosol. The problem is exacerbated during still days when there is no wind to dissipate the particles.

Preliminary evidence suggests that there are two main sources of Perth's haze problems. One is bushfires, during summer and early autumn. The second is particles from domestic heaters and motor vehicles; a problem in winter and spring.

The Division has set up haze measuring equipment at sites within Perth's existing air quality monitoring network. Two types of measurements are being made – the amount of light-scattering caused by aerosol (determined by nephelometers), and the chemical and physical characteristics of the fine particles. Usually it is particles with diameters smaller than 2.5 micrometres that cause urban visibility problems, so measurements are concentrating on these. However, larger particles, including sea salt, also contribute to haze as well as to health problems. So particles up to 10 micrometres are being included in the study.

Chemical analyses of aerosol in Perth air include determination of levels of inorganic ions (sources include sea salt, motor vehicles and biomass burning), metals (motor vehicles, biomass burning and soil), and carbon (biomass burning, industrial combustion, motor vehicles).

By identifying the nature of the haze and the relative contributions of various sources to the problem, Divisional scientists aim to be able to propose haze control strategies. The study will be completed by the end of 1995.

Rainwater studies

Having completed a major two-year study in Victoria's Latrobe Valley for the State Electricity Commission, the Division is conducting rainwater composition studies for Pacific Power in New South Wales' Hunter Valley and western coalfields.

Rainwater is collected automatically by a sophisticated automatic sampler designed by the Division. In the Hunter Valley, in addition to rainwater tests, measurements are being made of atmospheric gas concentrations and surface water and soil properties.

Dry deposition of pollutants such as sulfur dioxide and oxides of nitrogen can make a major contribution to the amount of acidity reaching the ground. To monitor these chemicals the Division constructed a batch of passive samplers. The samplers consist of a 25-millimetre diameter tube enclosing a range of filters. The filters protect specially impregnated paper onto which pollutant gases are passively adsorbed by molecular diffusion. Following exposure to the atmosphere, the filter is removed and its contents determined by chemical analysis.



Greg Ayers installs a passive air sampler designed to measure levels of acidic compounds in the air.

International connections

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Program scientists have presented invited papers at a number of international conferences and meetings during the reporting period. There have also been a number of lengthy exchange visits, which have been invaluable in promoting collaboration and the fruitful exchange of ideas.

The Division's presence in Asia grows steadily, with Environmental Consulting and Research Unit scientists completing a number of major air quality projects for the Australian International Development Assistance Bureau, the Asian Development Bank, overseas governments and power generating authorities. Countries in which we have been active include Indonesia, Japan, Korea, Malaysia, Taiwan, Thailand and Vietnam.

Acidification studies include an examination of power station emissions in the Klang Valley for Tenaga Nasional Berhad (the Malaysian National Electricity Authority), and a World Meteorological Organisation project in Indonesia. As part of the latter project, two members of the Indonesian Meteorological and Geophysical Agency spent a month training at our laboratories.

The Division has been instrumental in establishing a network of Australian and New Zealand air pollution modellers. A detailed listing of modellers and their expertise has been produced with support from the Department of Industry, Science and Technology.



Projects:

Large-scale Dynamics

Project Leader: Jorgen Frederiksen

Surface and Boundary-layer Processes

Project Leader: Ian Barton

Water Vapour and Climate

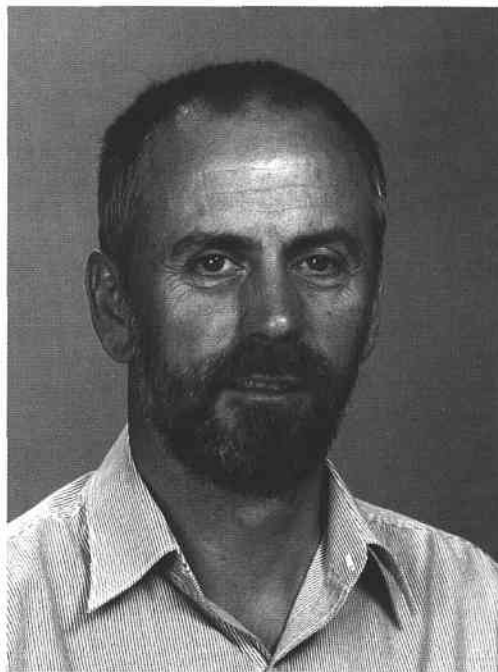
Project Leader: Denis O'Brien

Clouds and Radiation

Project Leader: Martin Platt

Cloud and Precipitation Modelling/Schemes

Project Leader: Brian Ryan



John Garratt, Program Leader

The amount of radiation striking and leaving the earth's surface and the top of the atmosphere is a crucial factor in determining our climate. It provides an important constraint for evaluating the performance of climate models. Moreover, the interaction of radiation with clouds, water vapour and the Earth's surface; precipitation processes; and large-scale dynamical processes all play key roles in the energy and hydrological cycles of the climate system.

There is still much to be learnt about these critical physical processes. Scientists in the Atmospheric Processes Program are carrying out research into selected atmospheric and surface processes related to large-scale motions, water vapour, clouds and radiation.

Our research is designed to identify key climatic processes and to understand the nature of interactions and feedbacks. We are achieving this with a combination of observational studies, theoretical advances and modelling activities. Observational work relies particularly on remote sensing from both the surface and space.

A number of remote sensing instruments have been developed during the reporting period.

The first stage of a feasibility study of an atmospheric pressure sensor is complete, and extensive testing has been carried out on the Airborne Hazard Detection System, designed to monitor the presence of volcanic ash in an aircraft's path. A new three-wavelength rapid scanning lidar and a sensitive, three-channel infrared-filter cloud radiometer have also been constructed.

The Group has participated in major field experiments, including the first phase of the Southern Ocean Cloud Experiment, which is designed to assess the likely impact of human activity on the distribution and composition of clouds.

The Atmospheric Processes Program is a major contributor to the CSIRO multi-Divisional Climate Change Research Program, which brings together scientific expertise across the organisation. The Program also has strong links with the Co-operative Research Centre for Southern Hemisphere Meteorology.

Radiation fluxes

Accurate representation of radiation fluxes at the surface is a critical attribute of a climate model. In order to assess how well models deal with these fluxes, the Division has acquired energy and radiation output fields from Australian and international climate models. The fields include monthly mean values for all grid points on the globe for up to a 10-year simulation period. They have been compared with observations including evaporation, radiation fluxes, screen temperature, precipitation and cloud cover.

Emerging from the study so far is the fact that net radiation at land surfaces is generally overestimated, apparently due to overestimates of the incoming solar radiation at the ground and to underestimates of the outgoing thermal radiation from the ground. Incorporation of a new land-biospheric scheme into the CSIRO9 climate model has improved the simulation of net radiation, and its partition into sensible heat and evaporation. This is partly because of the incorporation of vegetation processes, and the subsequent more realistic simulation of energy partitioning and hence near-surface air temperature.

Atmospheric Processes

The radiation budget at the Earth's surface

The biospheric scheme is relatively simple, but includes an up-to-date surface albedo specification, and the role of vegetation in the surface hydrology. During the reporting period, the Division's land-surface scheme was one of numerous schemes participating in the international Project for Intercomparison of Land-surface Parameterisation Schemes (PILPS). This project is ongoing, as is the development of our scheme to include sub-grid hydrology processes, and interactions between transpiration and photosynthesis.

A significant part of our studies to date has involved the use of high quality observations of surface radiation flux components, as well as land surface temperatures. Such observations are scarce, and there are national and international programs designed to acquire comprehensive data sets over a range of different landscapes.

Calibrating satellite data

The Division has established a ground station on a New South Wales sheep farm for making measurements to calibrate data received from satellites. At the site, near Hay, stands a 15-metre high tower, fitted with radiometers and temperature sensors. Additional instruments have been set up throughout a one-square kilometre area. They are programmed to record radiation and temperature readings every 200 seconds, regularly transmitting the data back to the Division by satellite. The measurement system, devised by the Division, is known as CSIDAT (CSIRO Data Acquisition and Telemetry Network). A second site for measuring short-wave and long-wave fluxes, to be operated in collaboration with the Bureau of Meteorology, has been chosen near Alice Springs.

Climate models, whether simple or complex, share a common problem of closure. At one extreme, a model which balances incoming and outgoing energy from the planet is only closed when the albedo (reflectance) of the planet is specified. At the other extreme, the problem of closure for a general circulation model is to express the turbulent fluxes of energy, momentum and moisture in terms of the forces driving the fluxes. The crucial property required of a closure strategy is that it must embody the physics but not be tuned to present day climate. Otherwise predictions of future climate could not be trusted.

Recently the Division has been investigating a simple model for climate closed by the hypothesis that the planet can be treated as a thermodynamic system whose steady states are states of

Sea-surface temperature measurements

Sea-surface temperature plays an important role in determining heat flux between the oceans and the atmosphere. More energy enters the atmosphere from the sea than from direct solar absorption.

The Along Track Scanning Radiometer (ATSR) was launched in July 1991 on the European Space Agency's ERS 1 satellite. The Division was part of the science team, led by Rutherford Appleton Laboratory, responsible for developing the radiometer, which was designed to provide accurate global sea-surface temperature data.

A feature of the ATSR is its dual view of the Earth's surface. As well as a downward looking scan, the instrument scans forwards, providing two views of each location. This process allows corrections to be made for the intervening atmosphere.

Comparisons of simultaneous sea-surface temperature measurements made by the ATSR and ship-borne radiometers show agreement to within 0.3°C. Divisional scientists have also checked ATSR data against temperature observations from drifting buoys.

Results indicate that the ATSR's dual view provides temperature measurements twice as accurate as those from current single view instruments.

The Division has been actively involved in developing a successor to replace the ATSR, which is approaching the end of its operational life. ATSR2 is scheduled for launch from French Guiana on board the European ERS-2 satellite early in 1995. Funding for the ATSR2 project comes from the Australian Space Office. An Adelaide company, British Aerospace Australia, constructed the electronic ground support system and AusSpace contributed to the optics.

maximum dissipation. These ideas have been pursued in three ways. Firstly, satellite data from the Earth Radiation Budget Experiment (ERBE) allowed the total entropy production of the planet to be measured. Secondly, a tight upper bound for entropy production was derived as a function of planetary albedo, and it was found that the planet's entropy production is close to the upper bound. Lastly, arguments from thermomechanics were adapted in an attempt to explain this finding concerning entropy production.

The Division is currently working on a new model that, unlike its predecessors, explicitly represents the crucial role of water vapour. Radiation parameterisations are based on sound physical principles and have been validated against remotely sensed data from ERBE and the International Satellite Cloud Climatology Project (ISCCP).

As clouds have a major influence on climate, considerable work is being done in Australia and overseas to elucidate their properties.

The Southern Ocean Cloud Experiment

The first phase of the Southern Ocean Cloud Experiment (SOCEX) took place during winter, 1993. Industrialisation, especially in the northern hemisphere, is increasing the concentration of cloud condensation nuclei. SOCEX is designed to investigate the likely impact of this on the distribution and composition of clouds.

Changes to climate may result from any alterations to cloud properties. The increase in cloud condensation nuclei concentration is likely to make clouds reflect more solar radiation back into space, countering to some extent any global warming.

The relatively clean air over the Southern Ocean offers a "natural laboratory" for studying the effects of varying concentrations of cloud

condensation nuclei. Divisional staff joined colleagues from Australia, New Zealand and the United States in northern Tasmania for SOCEX. While a Fokker research aircraft flew through boundary-layer clouds, carrying laser particle probes, radiometers, thermometers and other sensors, scientists on the ground measured aerosol particles, cloud condensation nuclei and lidar backscatter. A new CSIRO-designed computer graphics package continuously monitored atmospheric data and ensured that the plane flew through areas of greatest interest.

Winter was chosen as the time for the first phase of SOCEX as natural emissions from ocean plankton of dimethyl sulfide are low. This gas generates cloud nuclei. Hence, cloud nuclei levels were at a minimum.

The final phase of the experiment is scheduled for the summer of 1995, when emissions are high. Thus, comparisons can be made between clouds forming when there are low nuclei levels in the air and those that occur in air containing high concentrations of nuclei.

The F27 research aircraft being fitted with meteorological instruments in preparation for the Southern Ocean Cloud Experiment



Properties of tropical clouds

Kavieng, New Guinea, was home to a team of Divisional scientists early in 1993. They were collecting data on tropical clouds, including height, thickness and optical properties, as part of the US Atmospheric Radiation Measurement (ARM) Program. Also participating in the Program were colleagues from the US who measured winds, atmospheric temperature and humidity, cloud water, and surface radiation fluxes.

The measurements were timed to coincide with the international Coupled Ocean-Atmosphere

Response Experiment. ARM is a long-term investigation designed to improve the treatment of cloud radiative forcing and feedback processes in global climate models.

A new optical lidar and an infrared radiometer were used in New Guinea. The radiometer, which was paid for with ARM funds, was designed and constructed at the Division.

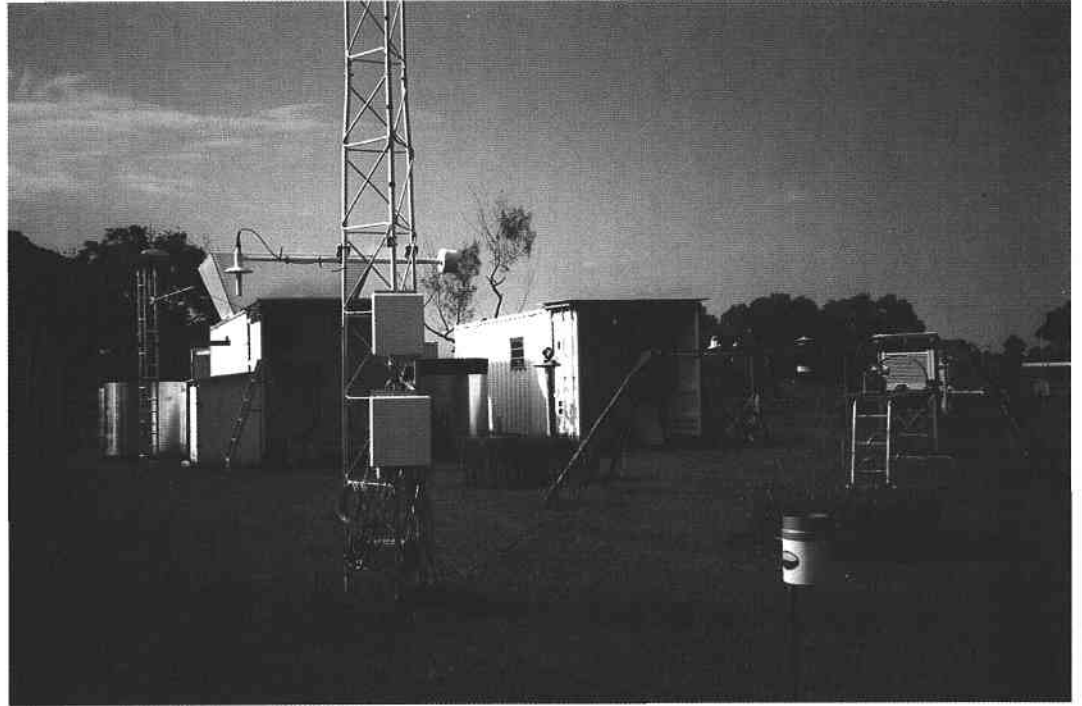
Kavieng is an ideal location for investigating the western Pacific warm pool, a region producing intense convection. The warm pool has a major impact on global weather patterns.

The tropopause, the boundary marking the top of the troposphere, is higher near the equator than elsewhere. The many-layered cirrus clouds that reached as high as 18 kilometres were of particular interest to the researchers.

The data collected will help establish the way in which clouds influence sea-surface temperatures,

radiative warming of the atmosphere, convection and the redistribution of water vapour. The data also form a valuable resource for the eventual establishment of a long-term ARM monitoring station on nearby Manus Island.

The scientific station for the Atmospheric Radiation Measurement (ARM) Program in Kavieng, New Guinea.



Modelling the behaviour of clouds

Atmospheric scientists readily acknowledge the need for improved representation of clouds in climate models. General circulation models and limited-area models have grid scales too coarse to explicitly treat convection and important cloud processes. Thus, modellers have been forced to stipulate variables to represent these features, arbitrarily assigning values to factors such as cloud albedo.

A better approach is to deal with clouds in the atmosphere as a coupled system, rather than as numerous discrete objects. The first step is to introduce into the models liquid water within clouds. Specifying an average droplet size allows the clouds' impact on radiation, both direct solar and re-emitted terrestrial, to be modelled.

The Division is currently using extensive observational datasets to develop advanced cloud parameterisations. The Southern Ocean Cloud Experiment is providing data on marine stratocumulus and cumulus clouds, while the Australian Winter Storms Experiment, conducted over Victoria's Baw Baw Plateau, offers information on mid-level clouds. The tropical data set on cirrus from Kavieng will also be used in addition to other international data sets. Parameterisation of tropical deep convection will be tested against results of ground-based and aircraft measurements from a planned Northern Territory field experiment.

Regional cloud climatologies

A cloud climatology using Advanced Very High Resolution Radiometer (AVHRR) satellite imagery is being used to test the development of clouds and cloud cover in the CSIRO limited-area model. In preliminary simulations, the model has been nested within European Centre for Medium Range Weather Forecasts (ECMWF) analyses and run at 30-kilometre resolution for a period of one month. The model's cloud cover was diagnosed from an explicit liquid water cloud scheme and from a relative humidity boxed cloud scheme.

Simulating extreme storms

Dam spillways must have sufficient capacity to safely carry away water during a sudden downpour. Water authorities rely on estimates of probable maximum precipitation for the design of spillways, which are expensive to build.

Probable maximum precipitation is an estimate of the highest rainfall event likely to occur over a catchment area. It is determined statistically from analysis of historical rainfall patterns. The Division is using computer-based numerical modelling techniques to investigate the validity of probable maximum precipitation estimates.

The first stage of the project involves examining the capability of numerical models to simulate extreme storms. Using Colorado State University's Regional Atmospheric Modelling System, Divisional scientists have endeavoured to simulate a flash flood that struck the area surrounding the New South Wales town of Dapto on 18 February 1985. Eight hundred millimetres of rain fell during the 48-hour storm.

The model was initialised using European Centre for Medium Range Weather Forecasts analyses interpolated to appropriate grid scales, which varied from 110 kilometres down to approximately 1.8 kilometres.

Extensive rainfall, windfield and satellite data have allowed thorough checking of the way in which the model simulates the storm. For example, windfield data come from nine anemometers spread at various elevations throughout the region.

Simulation results were pleasing, with accurate predictions of total rainfall. The meteorological processes thought to have been responsible for the extensive rainfall, namely the continuous generation and movement of convective cells throughout the region, were well simulated.



Debbie Abbs is modelling a number of severe storms that have occurred during the past decade.

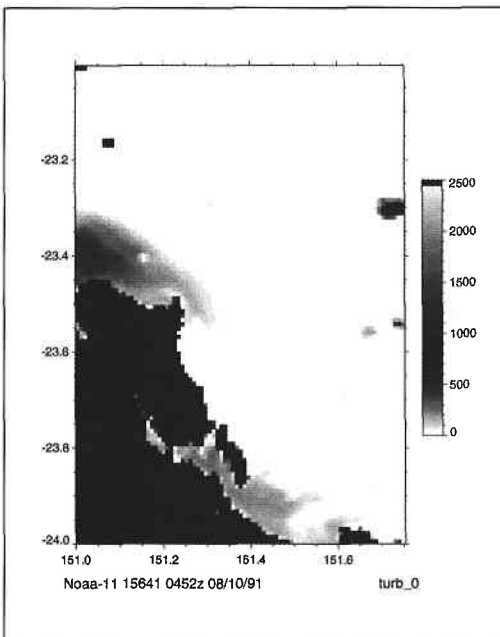
A study of the feasibility of using a satellite-mounted instrument to measure surface atmospheric pressure has been completed by the Division and VIPAC Engineers and Scientists Ltd. Optical, thermal and mechanical properties of the instrument have been examined and extensive modelling and instrumental analysis performed. The pressure sensor is designed to

measure absorption by oxygen in the atmosphere, from which the mass of air present above the ocean surface, and hence the atmospheric pressure, can be deduced.

A prototype sensor has been successfully tested in a series of ground and aircraft flights. The Australian Space Office supported this study.

Developing an atmospheric pressure sensor

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By examining satellite images of the sea off the Queensland coast, the Division is providing the Royal Australian Navy with turbidity data to help them survey Australia's coastline. In this image, the black area is the land. Grey regions indicate turbid water.

Funding for this work comes from the Urban Water Research Association of Australia.

The Division has developed a satellite-based technique to help the Royal Australian Navy survey Australia's coastline with its new airborne laser depth sounder. Nearly half of the continental shelf, approximately one million square kilometres, remains unsurveyed to acceptable standards.

The Navy surveys the ocean floor with a laser depth sounder mounted in an aircraft. If the sea is clear, the sounder can measure depths of up to 50 metres. However, turbidity reduces the sounder's depth capability.

By comparing turbidity readings made by the Navy off the coast of North Queensland with simultaneous satellite measurements, the Division has located parts of the ocean where turbidity is a problem. This information saves the Navy making fruitless measurement flights.

The next stage of this project is to examine the way in which turbidity varies throughout the year. There may be some regions where turbidity is always too high for sounding and others that can only be surveyed during certain months.

Assessing ocean turbidity

Large-scale dynamics

Divisional scientists are seeking to discover the mechanisms, causes and life-cycles of large-scale atmospheric disturbances. They are examining atmospheric behaviour on a global and hemispheric scale using dynamical model studies, general circulation model simulations, statistical techniques and observations.

The southern hemisphere forms the main focus of this research as it is not as well observed and documented as the northern hemisphere. Of course, the behaviour of our hemisphere has a direct bearing on our climate and climatic fluctuations.

The Australian monsoon lasts from late December to early March, bringing the wet season to the tropics. Atmospheric disturbances, such as low pressure areas or tropical cyclones, can intensify or reduce the impact of the monsoon.

In addition, repeating patterns of atmospheric fluctuations modulate rainfall, and determine active and break phases of the monsoon. These intraseasonal oscillations, with periods of between 30 and 60 days, may appear as cyclical wind behaviour patterns, or as variations in the intensity of outgoing longwave radiation.

The Division has produced the first theoretical model of the monsoon and intraseasonal oscillations. The two-level, primitive equation model has been used to generate features such as storm tracks, blocking, and global teleconnection patterns. The model incorporates global observations from the European Centre for Medium Range Weather Forecasts. Important applications of the model include improving the performance of general circulation models and investigating climate variability. The Group is contributing to the CSIRO Climate Variability and Impacts multi-Divisional Program.

International

Divisional scientists have strong links with several major international programs, including the US Atmospheric Radiation Measurement (ARM) Program, the Experimental Cloud Lidar Pilot Study (ECLIPS), the Global Energy and Water Cycle Experiment (GEWEX), the International Geosphere-Biosphere Program (IGBP) and the NASA Lidar-In-Space Technology Experiment (LITE). In many cases, our staff are active on Working Groups associated with these programs.

Improving climate model components such as cloud schemes clearly relies on collaborative

efforts between modellers, observational groups and those with expertise in the theoretical radiative characteristics of clouds. This collaboration is taking place within the Division and with colleagues in Australia and overseas.

Ongoing international collaboration with Rutherford Appleton Laboratory in Britain and the European Space Agency includes validation of data from the Along Track Scanning Radiometer and plans for the launch of its successor, ATSR2.

Projects:

Climate Change

Project Leader: John McGregor

Climate Variability

Project Leader: Hal Gordon

Ocean Modelling

Project Leaders:

Peter Baines and Stuart Godfrey
(Division of Oceanography)

Climate Impact

Project Leader: Barrie Pittock



Barrie Hunt, Program Leader

The climate system is extraordinarily complex. It involves interactions between the atmosphere, land, vegetation, the oceans and sea ice. Feedback loops abound, in which small variations in one component of the system may beget significant changes elsewhere.

Climate and climatic fluctuations have an enormous influence on our way of life and on our economy. The lengthy drought that has affected much of eastern Australia since 1991 is estimated to have cost three billion dollars in lost primary production. A multi-seasonal prediction scheme is being developed within the Climate Variability Group.

The Division's Climate Modelling Program seeks a better understanding of climate and its variations in order to assess the way in which climate is likely to change in future due to the enhanced greenhouse effect, and to reduce the impact of climatic variability.

The Division is aiming to develop a multi-seasonal prediction scheme, which will give warning of impending drought.

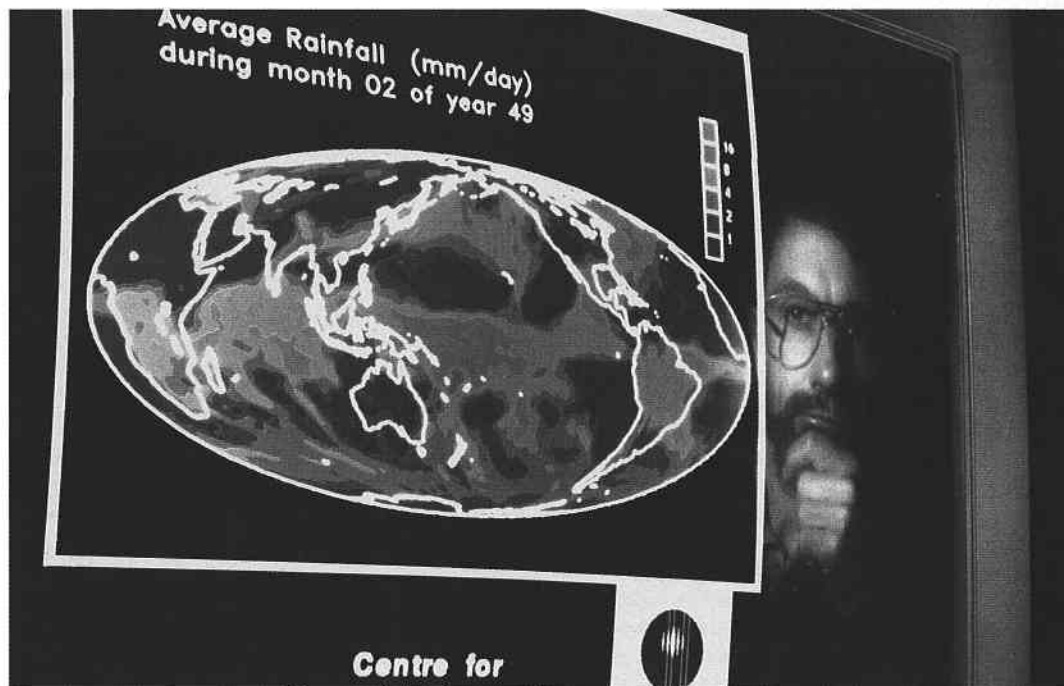


The Division maintains a world-class modelling facility, in which a range of models is being developed, tested and applied to a variety of problems.

By building upon results from general circulation models and limited-area models, the Climate Impact Group produces assessments of the likely impact of climatic change. The Group's scenarios have provided the basis for assessment studies performed by various groups throughout Australia and overseas and have played an important part in the policy-making process.

The Division is making a major contribution to a newly formed CSIRO multi-Divisional Program on Climatic Variability and Impacts, which encompasses a range of research activities examining climatic fluctuations and climatic extremes.

Introduction



Reflecting on rainfall patterns. Harvey Davies examines results from the CSIRO9 climate model.

The CSIRO9 climate model has now developed into a fully coupled atmospheric-oceanic global climatic model incorporating a biospheric scheme and sea-ice dynamics. Each component contains representations of complex physical processes and internal interactions, as well as external interactions with other components.

As part of the comprehensive testing process, rigorous comparisons have been made of CSIRO9's performance in greenhouse simulations with those of other high resolution models. Results from this exercise were pleasing; the model performs well by international standards. The model is also involved in a number of other international comparisons.

As well as assessing likely future climatic changes, recent experiments have investigated the impact of chaos on climate. These experiments involved simulating climate for the years 1979–1988 by driving the model with observed sea-surface temperatures and sea-ice distributions. The simulation was performed three times, with each run starting from slightly different initial conditions. Analysis indicates that sea-surface temperature anomalies can overcome chaotic influences, especially in the low latitude Pacific Ocean, where such anomalies are largest. In other regions, especially those influenced by El Niño Southern Oscillation (ENSO) events, averaging results from multiple runs helps improve signal-to-noise ratios, thereby reducing chaotic influences.

As ENSO events often have such a major impact on our climate, the influence of climatic change on ENSO is of great interest. Experiments have been conducted with CSIRO9 in which the typical sea-surface temperature anomalies associated with ENSO were superimposed upon conditions likely to be associated with global warming. Preliminary results suggest a modest enhancement of ENSO-related conditions can be expected.

An important application of climate models are multi-seasonal predictions. Current development work involves using the CSIRO model to "predict" Australian climate during 1992, using only observations available before the start of that year. Sub-models of the low-latitude Pacific Ocean and the Indian Ocean are being developed for coupling with the atmospheric model in order to produce a more physically based predictive scheme.

A two-year program aimed at developing Mark-III atmospheric and oceanic models has recently commenced. This work will involve finer scale resolutions as well as refined physical parameterisation schemes.

Limited-area modelling

Limited-area models allow simulations to be run of localised events, such as precipitation, which occur on scales far smaller than the resolution of global models (typically global models have grid points 500 kilometres apart).

In order to examine the likely regional impact of climate change, the limited-area model is nested within CSIRO9. The global model provides the broad-scale climate; the limited-area model uses these data to provide boundary values to produce regional climatic outcomes.

Limited-area models have another important use: they yield localised data that can be compared directly with observations, allowing assessments of how well various parameterisation schemes are performing.

Most nesting experiments are conducted at 125-kilometre resolution with nine vertical levels. However, some doubly-nested simulations of unusual weather phenomena such as east-coast lows and tropical cyclones have been performed at resolutions as fine as 30 kilometres, using 18 vertical levels.

In addition, 20-year nested model simulations have been run for January and July conditions across Australia. These simulations have been performed with present atmospheric levels of carbon dioxide and with double carbon dioxide concentrations, using diurnally varying radiation fluxes and improved cloud schemes. As well as presenting information about likely future changes, results from the simulations have also been useful for examinations of interannual climate variability.

Oceanic modelling

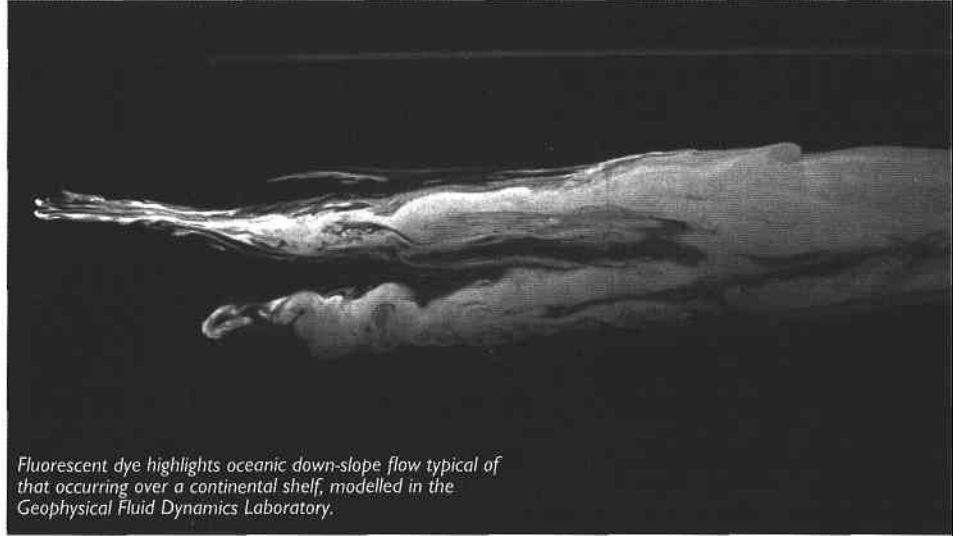
On time scales from decades to a thousand years or more, climate is affected by the way in which the deep ocean stores and transports heat.

Divisional scientists are working closely with colleagues from the Division of Oceanography to develop more realistic models of the ocean for predictive purposes, and for coupling with atmospheric models for full climate simulations.

Recent activities have included creation of fine resolution models of the equatorial Pacific Ocean and the Indian Ocean. The equatorial Pacific model will be particularly useful for investigating and forecasting ENSO phenomena and associated variability and the likely impact of

climate change on ENSO. The Indian Ocean model has been developed primarily to assist in developing multi-seasonal prediction methods.

It is not just computers that are being used to study oceanic behaviour – laboratory water tanks are also being employed. Studies in these tanks focus on particular phenomena, such as deep ocean circulation patterns, in order to identify the physical processes operating and thus better represent them in the numerical models.



Fluorescent dye highlights oceanic down-slope flow typical of that occurring over a continental shelf, modelled in the Geophysical Fluid Dynamics Laboratory.

The Division's Climate Impact Group aims to provide the best available estimates of the way in which climate change is likely to affect Australia, quantifying and reducing the uncertainties as far as possible. An important aspect of the Group's work is its preparation of local and regional climate change scenarios, which serve as the basis for impact studies. These scenarios are regularly made available to other research groups, and to the wider community.

Historical and palaeoclimatic data and results from global climate models are used extensively for scenario development. Particular emphasis is placed on satisfactory performance of climate models in simulating our present climate, including seasonal and inter-annual variations. The Group assesses potential changes in average

As part of the development program for our climate models, there are ongoing collaborative activities and comparison exercises with overseas modelling groups. An important exercise is the Atmospheric Model Intercomparison Program (AMIP), in which observed sea-surface temperatures from 1979-1988 are used to drive the models. Output from the models is compared, and assessments are made of the accuracy with which they simulate observations.

The Division is collaborating with Japan's National Research Institute for Earth Science and Disaster Prevention in an investigation of long-

term sea-surface temperature fluctuations and their effect on climate.

conditions and of variability, with a focus on extreme events. Changes to cold fronts, east-coast lows, tropical cyclones, and severe storms are priority issues, as is the likely behaviour of ENSO and the monsoon.

During the reporting period, the Climate Impact Group produced reports outlining the way in which climate change is likely to affect Victoria, Western Australia, New South Wales and the Northern Territory.

Topics examined recently by the Group include the impact of seasonal and daily rainfall changes on soil moisture and run-off, the effect that intensification of east coast lows may have on storm surge heights, and the likely influence of a warmer climate on Victorian snow fields.

term sea-surface temperature fluctuations and their effect on climate.

The Climate Impact Group has contributed to an international consultancy project for the Asian Development Bank examining potential impacts of climate change on water resources and agriculture in Bangladesh, India, Indonesia, Malaysia, Pakistan, Philippines, Sri Lanka and Vietnam. The study highlighted the need for better information on the effects of global warming on the behaviour of ENSO and tropical cyclones, as well as the significance of possible increases in rainfall intensity.

Projects:

Radiatively Active Gases

Project Leader: Ian Enting

Scientific Support for the Cape Grim Baseline Air Pollution Station

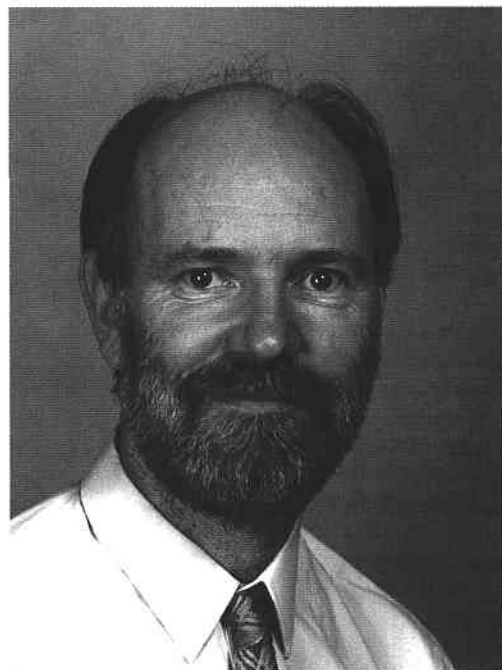
Project Leader: Paul Fraser

Terrestrial Sources and Sinks of Climatically Active Trace Gases

Project Leader: Ian Galbally

Climatically Active Aerosol

Project Leader: Greg Ayers



Ian Galbally, Program Leader

Introduction

The province of the Global Atmospheric Change Program is the chemistry of the troposphere and the stratosphere. Activities include measurements of a range of greenhouse and ozone-depleting gases and aerosol, investigations of chemical transformations in the atmosphere, sources and sinks and modelling studies.

Our knowledge of current levels of trace gases in the air and their isotopic composition comes from analysis of samples collected at the Cape Grim Baseline Air Pollution Station in north-western Tasmania, and from an extensive global sampling network that stretches from virtually the north pole to the south pole. The Cape Grim station, jointly managed by the Bureau of Meteorology and CSIRO, began operation in the 1970s.

To find out what the atmosphere was like before regular sampling began, Program scientists extract air from ice cores supplied by the Australian Antarctic Division. Air trapped in the cores may date from as recently as the 1970s or from thousands and even tens of thousands of years ago.

To help interpret our measurements, the Program has developed sophisticated numerical models of atmospheric transport and exchange.

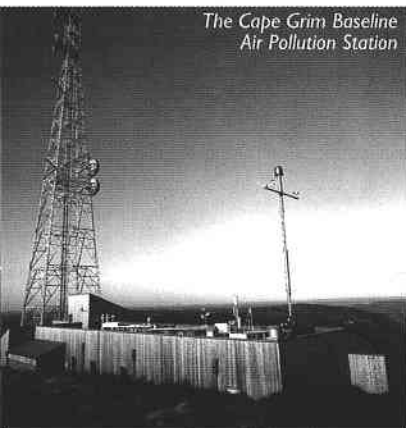
These models are providing valuable information about sources and sinks of greenhouse gases and are supplying predictions of likely future concentrations. This work is carried out in partnership with the Co-operative Research Centre for Southern Hemisphere Meteorology.

There is still much to be learnt about sources and sinks of greenhouse gases in Australia. The Program has run field experiments to quantify gas emission rates and examine processes controlling release of climatically active trace gases from natural, agricultural, urban and industrial systems. We are also seeking to establish the mechanism by which oceanic phytoplankton modulate climate over the Southern Ocean by their release of dimethyl sulfide gas, which leads to the formation of cloud condensation nuclei.

Studies of the efficacy of Australian and international efforts aimed at minimising changes in global atmospheric composition and the consequent environmental impacts are an important component of the Program. Scientists from the Program have been actively involved with both the National Greenhouse Gas Inventory Committee and the Intergovernmental Panel on Climate Change.

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The Cape Grim Baseline Air Pollution Station



Greenhouse and ozone-depleting gases

Methane's growth rate slows

Measurements of atmospheric levels of methane show a marked slowdown of the global growth rate during 1992. The data are from sites in a global cooperative air sampling network and from shipboard readings. The Division has participated in this project, which is being led by the Climate Monitoring and Diagnostic Laboratory at the U.S. National Oceanic and Atmospheric Administration (NOAA).

The average growth rate in atmospheric methane in the northern hemisphere between 1983 and 1991 was 11.6 ± 0.2 parts per billion (ppb) per year. In 1992 the growth rate fell to 1.8 ± 1.6 ppb. In the southern hemisphere the change in growth rate was more modest. Between 1983 and 1991 it was 11.1 ± 0.2 ppb per year. Last year it was 7.7 ± 1.0 ppb.

Methane is an important greenhouse gas. Its concentration has risen from about 750 ppb before the industrial revolution to an average of 1700 ppb today. In addition to methane's direct radiation forcing, chemical reactions involving methane lead to the production of tropospheric ozone, and stratospheric water vapour, both of which are themselves greenhouse gases.

The reasons for the slowdown in methane growth are not clear. The most likely explanation, however, is reduction of natural gas leakage from the former Soviet Union's pipeline distribution network. This follows a major effort to patch a very leaky network of natural gas pipes. In addition, coal production in the former Soviet Union has fallen since 1988. Lower surface air temperatures following the eruption in June 1991 of Mount Pinatubo may have reduced methane release from wetlands.

Isotopic measurements of atmospheric methane are underway to determine the cause of the sudden change to methane's atmospheric accumulation rate. In addition, studies of individual methane sources will contribute to a more accurate global budget of this important gas.

CFC measurements

Recent monitoring results from Cape Grim indicate that growth rates of all major chlorine- and bromine-containing ozone-depleting substances in the troposphere are slowing or have stopped. This is a promising sign, indicating that the Montreal Protocol, an international agreement aimed at cutting back production of substances harmful to the ozone layer, is meeting its objectives.

The Division's projections indicate that tropospheric chlorine in the southern hemisphere will stop growing between 1996 and 1999. Northern hemispheric chlorine is likely to stop growing a year or so earlier than this.

Monitoring release and uptake of greenhouse gases by soil in Victoria's Wombat State Forest.



Stratospheric chlorine levels are likely to peak some three to five years after maximum concentrations are reached in the troposphere. However, chlorine in the stratosphere will remain sufficiently high to initiate springtime Antarctic ozone holes until at least 2015.

In an effort to learn more about Antarctic ozone depletion, Divisional scientists are participating in the Airborne Southern Hemisphere Ozone Experiment, led by the U.S. National Aeronautical and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA).

The experiment is being conducted in four phases throughout 1994, allowing scientists to monitor conditions prior to, and then during, the Antarctic ozone hole. Measurements are being made from a sophisticated ER-2 high-altitude plane, flying from Christchurch, New Zealand.

As well as CSIRO, other Australian participants in the experiment are the Bureau of Meteorology and the Cooperative Research Centre for Southern Hemisphere Meteorology.

Measuring natural greenhouse gas emissions

The Wombat State Forest, in central Victoria, is the location for a field experiment examining the long-term impact of prescribed burning on gas uptake and release by soil. The burning is carried out in forests to reduce the amount of combustible material so that bushfires are easier to control.

The field experiment is testing the hypothesis that burning changes chemical processes occurring in the top layer of soil, resulting in greater emissions of nitrous oxide. The effect of burning on uptake of methane by the soil is unknown, but will be determined in this experiment.

Two similar nearby plots were chosen, each 50 metres square. Measurements were made of fluxes of nitrous oxide, carbon dioxide and methane. Then one plot was burnt in spring as usual, while the other was left in its natural state. During subsequent field trips in summer, autumn, winter, and spring scientists have repeated their measurements.

To measure gas fluxes, the project team uses automatically operated chambers that enclose vegetation and soil.

Gases in the chambers when open to the air and when closed are sampled during a 24-hour period. The samples are then transported to the Division's laboratories for analysis. In addition to the air analyses, soil tests and biological modelling are being performed.

The results of this experiment, which is being conducted in collaboration with scientists from the Victorian Department of Conservation and Natural Resources, should make a valuable contribution to estimates of Australian nitrous oxide and methane emissions and to global budgets of both gases.

Greenhouse gas inventory for Victoria

As a signatory to the Framework Convention on Climate Change, Australia is required to develop a national inventory quantifying our sources and sinks of greenhouse gases. By identifying processes, activities and sectors that contribute to the enhanced greenhouse effect, policy makers will be able to monitor and evaluate the effectiveness of mitigation policies and follow progress towards meeting any reduction targets that are set.

In parallel with the national exercise, the Victorian Government, through the Environment Protection Authority, commissioned the Division to produce an inventory for the State for 1987-88, 1989-90 and 1990-91. The inventory includes detailed estimates for carbon dioxide, methane, nitrous oxide, carbon monoxide, oxides of nitrogen, chlorofluorocarbons and volatile organic compounds. Activities assessed were energy, industry, solvents, agriculture, land use and forestry, and waste.

According to the inventory, Victoria's carbon dioxide emissions reflected economic activity in the State, growing between 1987-88 and 1989-90, then falling between 1989-90 and 1990-91. Release of the gas from land clearing has declined while methane release from landfills rose significantly. The growth of methane release may diminish as recovery processes are instituted: approximately 30 per cent of methane produced from sewage in the State is captured and used to generate energy.

The Victorian inventory was produced with assistance from the Bureau of Resource Sciences.

Atmospheric history in Antarctic ice

Ice cores studied in collaboration with the Australian Antarctic Division continue to provide fascinating information about changes throughout history to concentrations of gases such as carbon dioxide and methane. Currently the Division is examining air from cores drilled at Law Dome in East Antarctica, where the rate of snow fall is very high. As a result, the age of the air can be precisely determined. The most recently trapped air in the 234-metre long DE08 core originates from the 1970s, while the air at the bottom of the core is approximately 1000 years old.

In the Division's Ice Core Extraction Laboratory (ICELAB) air is removed from the core, dried and analysed in the Global Atmospheric Sampling Laboratory (GASLAB). Snow that falls in summer is rich in heavy isotopes of oxygen so annual patterns in the concentration of this isotope enable the age of the ice, and hence its trapped air, to be determined. Supporting evidence about the age comes from particles released by major volcanic eruptions.

The ice record clearly shows the variations in carbon dioxide concentrations, including a drop during the Little Ice Age (~1600-1800), fluctuations this century, and the rapid rise commencing in the 1950s.

Determining the rate of air entrapment in ice

One of the problems facing scientists studying past atmospheric gas concentrations is establishing how long it takes for air to be completely sealed within ice and out of contact with the atmosphere above. The rate of entrapment affects both the age of air in the core and the age spread of the air.

Divisional scientists are seeking a solution to this problem by measuring the abundance of the radioactive carbon-14 isotope in trapped air. The results can then be compared with available records of carbon-14 isotope levels in other terrestrial systems. Atmospheric levels of the isotope rose sharply during the above-ground nuclear tests of the 1950s and 1960s. The rate of decay of carbon-14 is known, so once levels in ice-core air are measured, the age can be deduced accurately.

Carbon-14 is present in air in such tiny concentrations that new techniques for handling and chemical processing have had to be devised. Accelerator mass-spectrometry is being performed by the Australian Nuclear Science and Technology Organisation (ANSTO). In conjunction with these measurements, numerical models of the gas trapping process during ice formation are being developed.

The accelerator mass-spectrometry project is an adjunct to the more fundamental firn diffusion studies with models and with firn air samples. The latter studies involve close collaboration with the Australian Antarctic Division, Australian National University, and ANSTO. There are also strong links with French scientific agencies.

Modelling emissions of carbon dioxide

Atmospheric levels of carbon dioxide are accurately known from worldwide observatories including Cape Grim. Modelling techniques developed by the Division are using this information to establish where the carbon dioxide is coming from, and what happens to it once it is in the atmosphere. Thus, the models are providing valuable new information about the way in which carbon is transferred between land, the biosphere, oceans and the atmosphere.

At the same time, other models are enabling the Division to estimate the accuracy of current estimates of global carbon dioxide release, and hence the likely effectiveness of international efforts aimed at reducing emissions of greenhouse gases. Results from the Division's models are being used by the Intergovernmental Panel on Climate Change, the international body drawing together the latest information about the greenhouse effect, to assess what emission reductions will be needed if carbon dioxide concentrations in the atmosphere are to be stabilised at, for example, 650 parts per million (the current concentration of carbon dioxide is 355 parts per million).

This work is being supported by Multi-Function Polis Australia, which has linked the Divisional team with scientists from the Japanese Ministry of International Trade and Industry.

Uptake of carbon dioxide by plants and the oceans

By examining changes to the ratio of carbon-13 to carbon-12 in atmospheric carbon dioxide, the Division is providing a new insight into the carbon cycle and the role played by plants and the oceans. The research suggests that changes in ocean exchange have been the dominant influence in determining the large year-to-year changes over the past decade in atmospheric levels of carbon dioxide.

Measurements are based on recordings of changes in the isotopic make-up of carbon atoms in the global atmosphere. Plant material has less carbon-13 than carbon-12 as a result of plants' preference for the lighter isotope during photosynthesis. The release of huge amounts of carbon dioxide from ancient plant material in the form of oil and coal dilutes the carbon-13 in the atmosphere. If modern plants take up extra carbon, they tend to offset this dilution.

The new results are based on an exhaustive investigation of mass spectrometry techniques revealing several unrecognised problems and resulting in the formulation – and acceptance by the International Atomic Energy Agency – of protocols for measurement and correction of atmospheric trace gas isotope measurements.

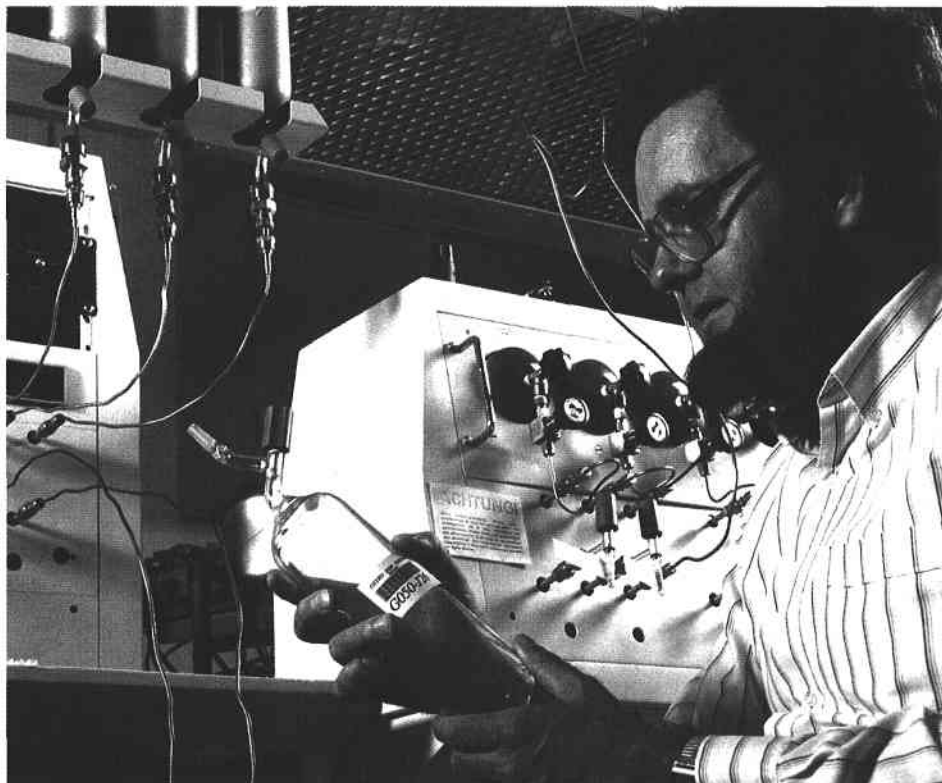
Air samples come from Cape Grim and from a global network established with support of the



Colin Allison measures the isotopic make-up of carbon dioxide with GASLAB's mass spectrometer.

Australian National Energy Research Development and Demonstration Council. Analysis has been done using GASLAB's sophisticated mass spectrometer.

The research suggests that variations in oceanic upwelling, associated with El Niño make a major contribution to year-to-year atmospheric carbon dioxide fluctuations. During early phases of El Niños in 1982, 1986, and 1991-92, the normal upwelling of cold carbon dioxide-rich water in the tropical Pacific was reduced, which, globally resembled an increased carbon dioxide-uptake by oceans.



Ian Enting prepares a gas flask for analysis. Ian's models have helped establish sources and sinks of carbon dioxide and likely future concentrations of the gas.

Piecing together the carbon cycle

Particles in our air

Aerosol affects climate both directly and indirectly. Direct effects include scattering and absorption of incoming shortwave radiation, and absorption of longwave radiation emitted from earth. Indirectly, aerosol may modify cloud optical properties, affect pre-cipitation, and influence concentrations of some greenhouse gases through surface reactions.

Recent measurements suggest that optical properties of stratus cloud over the Southern Ocean are influenced by emissions of sulfur from ocean algae. These emissions are likely to increase if the ocean surface warms. The Division's initial calculations suggest that a doubling of marine cloud condensation nuclei concentrations would counteract climate forcing caused by a doubling of carbon dioxide.

The Division is currently probing physical, chemical and meteorological factors regulating cloud condensation nuclei formation. This work involves a number of long-term measurement programs at Cape Grim, Macquarie Island and Antarctica. A key process being unravelled is the photochemistry of ozone and the production and loss of free radicals in the marine boundary layer. The first observations of ozone destruction and subsequent hydrogen peroxide production from peroxy radicals were made at Cape Grim recently.

A major photochemistry experiment at Cape Grim building on this study will begin in 1995, examining formation and destruction of ozone, including direct measurements of peroxy radicals and other key atmospheric constituents. These observations should greatly improve our understanding of sulfur oxidation in the marine boundary layer.

International connections

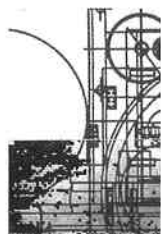
Extensive collaborative programs link Divisional scientists with overseas colleagues. The strong ongoing links with the Climate Monitoring and Diagnostics Laboratory of the National Oceanic and Atmospheric Administration through our Cape Grim activities are being extended to other nations that are establishing similar programs as part of the WMO Global Atmosphere Watch.

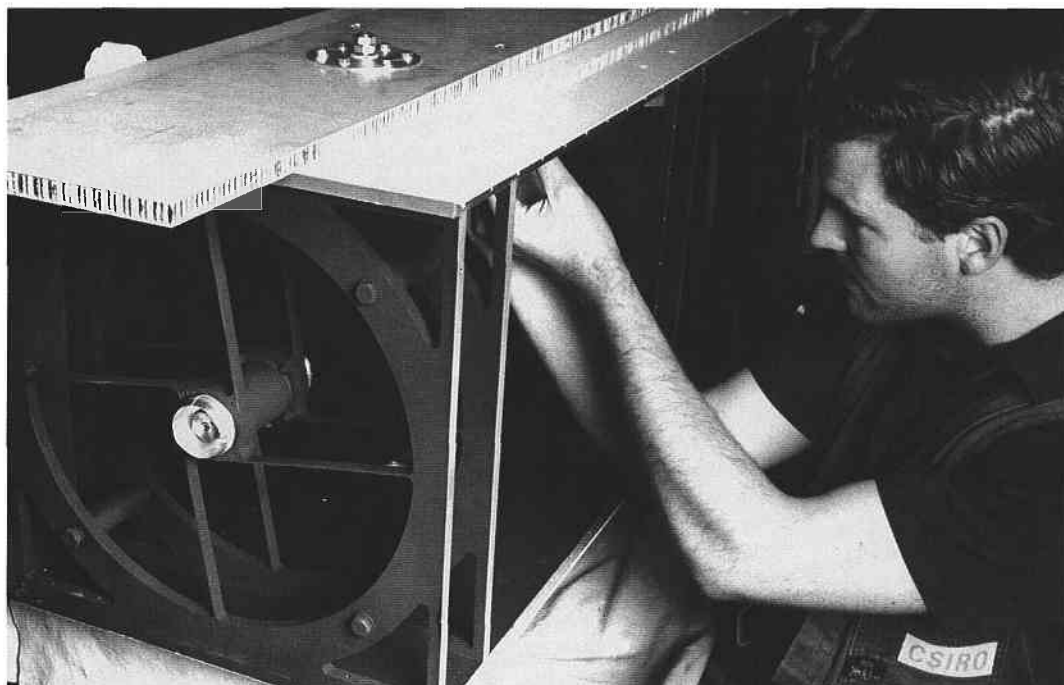
The Program plays a substantial role in international and national atmospheric chemistry activities. As well as participating in international atmospheric chemistry experiments and modelling studies, the Program is represented on the committees of Global Atmosphere Watch and the International Global Atmospheric Chemistry (IGAC) Project of the International Geosphere-Biosphere Program.

Multi Function Polis Australia supports research being performed in collaboration with the Japanese National Institute for Resources and Environment. Contributing projects include global transport modelling of greenhouse gases, development of climatically active aerosol models, and intercalibration of gas standards.

GASLAB is an integral part of international programs designed to monitor the planet's atmospheric health. Samples are collected in collaboration with scientific agencies in Canada, India, UK and the USA. International scientists regularly visit the laboratory. In turn, a number of our staff have had the opportunity to spend time at facilities overseas.

Program scientists have taken lead roles in a number of World Meteorological Organisation projects dealing with issues such as radiative forcing and gas measurements.





Above: Patrick Bradley works on the telescope assembly of the Division's new lidar in the mechanical workshop.

Below: Divisional Finance Manager Ramsay Jack (seated), Colin Yates (Human Resources Manager) and Judith Foletti (Travel Officer).



The Division's administration and engineering services group oversees the following areas: human resources, financial resources and commercialisation and technology transfer, and design and construction activities.

The complex and specialised nature of much of the Division's work often means that equipment must be designed and purpose-built in-house. This is carried out by experienced staff in sophisticated mechanical and electronics laboratories. A number of the instruments designed and built on site are being produced and marketed under licence by private companies.

Administration and Engineering

The Scientific Services Group supports the Divisional research effort by providing scientific administration support; communication and information activities; graphics and photographic services; library facilities; and information technology services.

Communication is an integral part of the scientific process. The Division actively seeks to promote the importance and relevance of the results of our research and to encourage feedback from stakeholders. A range of mechanisms are used to foster close relationships with stakeholders who include government, business and industry, the general public, scientific peers, other parts of CSIRO, and international agencies.

The Divisional library houses Australia's largest collection of atmospheric science journals and monographs. In support of the Division's research, the library also offers an extensive range of information services. This includes a comprehensive collection of monographs and journals, as well as CD ROMs and access to computerised catalogues and databases.

The Computer Services Group manages and provides support for a network of locally installed computer servers and graphics workstations, as well as remote supercomputers. A dedicated link connects the Division to a CRAY supercomputer, and to the Australian Academic Research network (AARNet), which connects universities and research organisations throughout Australia and overseas.

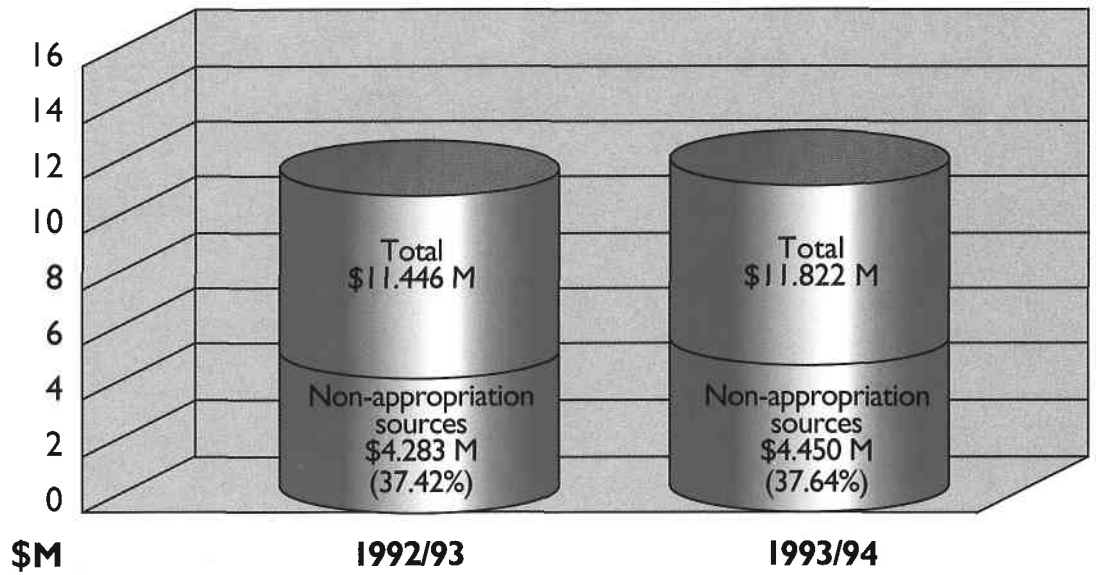
Paul Holper, Communication Manager (left) and Chris Mitchell, Coordinator, CSIRO Climate Change Research Program.



Scientific Services

Finances

Expenditure



External Funding Agencies

- Australian National University (NGAC)
- Australian Water Resources Advisory Council
- Bureau of Meteorology
- Climate Institute (Washington, USA) (For Asian Development Bank)
- Colorado State University
- Conservation Commission of the Northern Territory
- Defence Science and Technology Organisation
- Department of Agriculture and Rural Affairs (Vic.)
- Department of Defence
- Department of Industry, Technology and Commerce
- Department of Primary Industry and Energy
- Department of the Arts, Sport, the Environment and Territories
- Department of Water Resources (NSW)
- Electricity Commission (WA)
- Environment Protection Authority (Vic.)
- Environment Protection Authority (WA)
- International Atomic Energy Agency
- Melbourne Water
- Mount Isa Mines Ltd
- Rural Industries Research and Development Corporation
- Shell Company Australia Ltd
- State Electricity Commission (Vic.)
- State Pollution Control Commission (NSW)
- Tenaga Nasional Berhad (Malaysia)
- United States Department of Energy
- University of East Anglia
- University of New South Wales (ARC)
- Urban Water Research Association of Australia
- Wool Research and Development Fund
- World Meteorological Organisation



This list does not include abstracts of conference papers, book reviews, Divisional information sheets and internal and non-technical Divisional reports.

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* Joined the Division during the reporting period,
 1 July 1992 – 30 June 1994

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      tzp = scaled(zp,z,kz)
      ipnext=i
      do nos=1,nsorce

```

```

c----- calculate plume width
      sigxpr = 0.6*(zplu(nos)-zs(nos))
      sigypr = 0.6*(zplu(nos)-zs(nos))
      sigzpr = 0.3*(zplu(nos)-zs(nos))
      sigxpr = sqrt(sigxi(nos)**2+sigxpr**2)
      sigypr = sqrt(sigyi(nos)**2+sigypr**2)
      sigzpr = sqrt(sigzi(nos)**2+sigzpr**2)
c----- calculate mean velocity at plume height
      zp = zplu(nos)*origh/(origh-tosree(nos))
      tzp = scaled(zp,z,kz)
      uint = intrp3d(up,sx(nos),sy(nos),tzp)
      vint = intrp3d(vp,sx(nos),sy(nos),tzp)
      wint = intrp3d(wp,(sx(nos)-0.5),(sy(nos)-0.5),tzp)

```

```

c----- calculate source position in real units
      ix = sx(nos)
      x = x(ix)+(sx(nos)-ix)*(x(ix+1)-x(ix))
      iy = sy(nos)
      y = y(iy)+(sy(nos)-iy)*(y(iy+1)-y(iy))
      iz = zs(nos)
      z = z(iz)+(zs(nos)-z(iz))*(z(iz+1)-z(iz))

```

```

c----- calculate particle position
      do i=1,ipnext+1
      if (i .eq. 1) then
      ipnext=ipnext+1
      if (i .eq. 1) then
      ipnext=ipnext+1
      if (ipnext.gt.npart) ipnext=ipnext
      if (ipnext.gt.npart) then
      write(*,*) '*** Error: npart < nt
      stop
      endif

```

```

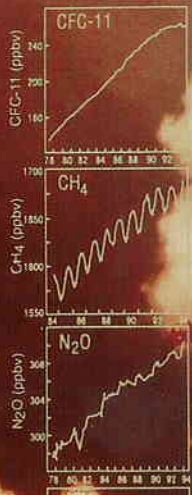
c----- get some random numbers for later
      upp = xran(kcou)
      keou = mod(kcou,ntan) + 1
      vpp = xran(kcou)
      keou = mod(kcou,ntan) + 1
      wpp = xran(kcou)
      keou = mod(kcou,ntan) + 1
      mass = wpp*(keou,ntan) + 1
      mass = mass*(mass*dimov/iperdt)
      mass = mass*(mass*dimov/iperdt)

```

```

c----- calculate particle position
      do i=1,ipnext+1
      if (i .eq. 1) then
      ipnext=ipnext+1
      if (i .eq. 1) then
      ipnext=ipnext+1
      if (ipnext.gt.npart) ipnext=ipnext
      if (ipnext.gt.npart) then
      write(*,*) '*** Error: npart < nt
      stop
      endif

```



zp = zp

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