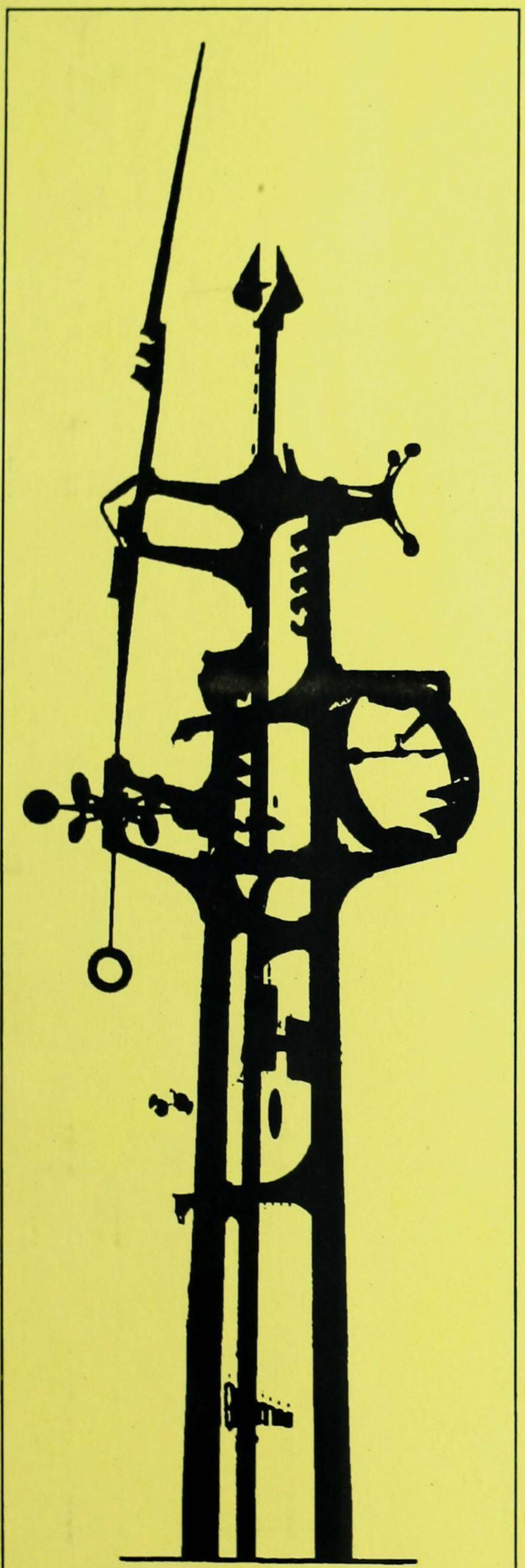

AIR QUALITY
RESEARCH BRANCH

ANNUAL REPORT
1995-96

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AIR QUALITY RESEARCH BRANCH

ANNUAL REPORT

1995/96

Compiled by
Malcolm E. Still

December 1996

Air Quality Research Branch
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario, Canada M3H 5T4

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ANNUAL REPORT

1995/96

1.0 FOREWORD

1.1 AIR QUALITY RESEARCH BRANCH

The atmosphere is a unique part of the environment in that it has no boundaries. Pollution moves from one place to another in days. Actions that degrade the atmosphere today affect the entire planet tomorrow. Several air pollution issues face both Canadians and global citizens, namely, acid deposition, hazardous air pollutants, tropospheric ozone (smog), stratospheric ozone and climate change. These issues are the focus of the national research program at the Air Quality Research Branch of the Atmospheric Environment Service, Environment Canada.

The Branch was formed in 1971, originally to study acid deposition, and now this is the largest group of atmospheric specialists in Canada with about 35% of these specialists having advanced degrees to the doctorate level. With an international reputation established, the Branch makes a significant contribution to the advancement of the understanding of air pollution problems. The vision of this research community is to advance scientific knowledge on air quality for the well-being of Canadians. Through its research, the Branch provides Canadians, including policy makers, with scientific information and advice on air quality issues as a basis for informed decision-making.

Measurements from laboratory and field experiments, and including monitoring networks, allow scientists to assess the extent of pollution problems and to improve their understanding of the processes. This understanding can be built into a computer model that simulates reality and can be tested against actual measurements. Once confidence is gained in the model's performance, it can be used to help in policy decisions by predicting the benefits of different pollution control strategies. After control measures have been implemented, the Branch continues monitoring pollutants to make sure that the levels are being reduced to acceptable limits. Scientists analyse these data so as to inform the policy-makers on the success of the controls. Also data from these networks are used to inform the public regarding the state of the environment. Examples of these services are the Ozone Watch and the UV Index.

The main laboratories are located on the outskirts of Metropolitan Toronto (North York), with smaller facilities in Egbert, Borden and Fraserdale, Ont., and in Alert and Eureka, N.W.T. These laboratories contain state-of-the-art equipment that, in a few cases, has been designed by Branch staff and, subsequently, been produced by Canadian industry. These laboratories often play host to international scientists with whom the Branch collaborates. The Branch has always striven to build strong partnerships, both nationally and internationally, to optimize our financial and human resources. The DOE Regions play a major role in co-operative projects that are national in nature, particularly those that have a regional aspect.

1.2 RESOURCES REPORT

- K. Ford, L. Grittani, W. Hart and M. Still

During the year, Branch staff participated in 116 international business meetings, workshops and scientific projects. In addition, the scientific staff participated in sixty-two conferences, presenting papers at many of them. Of these conferences thirteen were held in Canada and twenty-seven in the U.S.

This year the Branch implemented the federal government's Program Review with the departure of 10 employees, reducing the staff complement to 109 full-time equivalents. The Branch had the opportunity to hire two "affected" employees from other Directorates for two-year assignments under the Work Opportunity Program. To aid our research program, the Branch added to their full-time staff 10 post-doctoral fellows and several guest scientists from other countries. Over the year, 25 university and college students also worked within the Branch.

Dr. Don McKay is new Branch Director

In August 1995, Dr. Hans Martin was seconded to Bonn, Germany, for a two to four-year tenure as Counsellor of Science & Technology for the Department of Foreign Affairs and International Trade. Dr. Don McKay took over as Director in January 1996. Dr. Keith Puckett returned from his assignment in the Policy, Program and International Affairs Branch and Dr. Ann McMillan will commence a two-year assignment in his place. Dr. S. Venkatesh from the Meteorological Services Research Branch will fill in for Ann McMillan as the Chief of the Modelling and Integration Research Division. In November 1995, Dr. Douglas Whelpdale, moved to the Climate Research Branch and, subsequently, took on a one-year assignment as Director of that Branch.

The Air Quality Research Branch began the year with a budget of $16,000K: salary ($6,400K), operating ($7,500K) and capital ($2,100K). This budget represented a decrease of about $1,200K from last year's initial allocations, largely attributable to the government's Program Review. In addition to the initial allocations, the Branch received funds for special projects:

- Atmospheric Environment Program Strategy Capital: $108K for the Great Lakes program; $59K for Phase II of the Chemistry Laboratory moves; and $170K for the Brewer Ozone & UV Network Control System.
- The Air Toxics program received $700K from the Great Lakes Action Plan, $200K from the Air Issues Branch, and $400K from the Department of Indian Affairs and Northern Development (DIAND)
- The Climate Research Branch provided $200K to support the Global Warming initiative.

Branch has budget of $18 million

New laboratories are now in operation in a building adjacent to the building at 4905 Dufferin Street. Phase I began with the breaking of ground in the fall of 1993 and ended with all the laboratories in operation by the spring of 1995. Seven laboratories moved in Phase I and 5 more will move in Phase II. Phase II is expected to be fully implemented by fall 1997. The building has two floors and a basement. At the moment, occupancy is about 60% of the two main floors. Phase II will fully use the remaining space on these floors.

This building was constructed as health and safety requirements were not being met by having the chemical analysis laboratories located in the main building at 4905 Dufferin Street. After an analysis of the various options, it was decided to build adjacent to the present building. This building is specifically designed to house the laboratories that the Branch requires to analyse samples for trace atmospheric pollutants from field projects and from networks, and to develop methods for the measurement and analysis of these atmospheric constituents.

This year, the Branch has set up a web page that describes the many facets of the Branch's activities and accomplishments, including the most recent annual reports and publication lists. This site can be accessed through the Environment Canada - Downsview web site.

1.3 AWARDS

For 1995, the Branch presented two All-Seasons Research Awards to the following persons:

Bill Burrows who developed two important air quality forecasting tools - the UV Index and the Smog Advisory. Both forecasts are being used operationally. One of the forecasts, the UV Index, has gained international recognition. Bill's cooperation with scientists and technologists in the Air Quality Research Branch and at the Canadian Meteorological Centre was a key factor in the success of these two forecasts.

Ray Hoff who has led the Branch's research into the optical properties of aerosols and gases in the atmosphere. He also has been involved in research into the pathways and fates of toxic organic and elemental chemicals in the environment. Due to his leadership, international recognition and respect has been shown for major research programs in the Branch, such as Arctic Haze, airborne and spaceborne lidar, atmospheric deposition to the Great Lakes, atmospheric visibility and dispersion of pollutants. An example of his leadership was that he was the only Canadian Principal Investigator for the NASA project: Laser In-Space Technology Experiment (LITE).

2.0 THE ISSUES

2.0.1 ACID DEPOSITION

The main constituents of acid deposition, sulphur and nitrogen oxides, have as their main sources power plants, non-ferrous smelters and automobiles. Sulphur dioxide is produced from burning sulphur-containing coal and smelting sulphur-containing ore. While airborne, it reacts with water to form sulphuric acid. Similarly, nitrogen oxides, released mainly during high-temperature fuel combustion, form nitric acid in the air. Acidifying substances stay in the air for days, sometimes travelling thousands of kilometres. Thus, pollutants produced in one country are often transported into and impact upon another.

Studies in the 1970s showed acid rain to be an enormous problem in Canada, mainly due to sulphur dioxide emissions. In 1985, the Canadian federal and provincial governments agreed to cap sulphur dioxide emissions produced in Canada to 3.2 million tonnes by 2000. Emissions in eastern Canada are now within 16% of the program target. Based on the Canada/U.S. Agreement on Air Quality, the U.S. will reduce the 1990 level of 21 million tonnes by 9 million tonnes by 2000. Canada has also reduced nitrogen oxide emissions by placing pollution controls on automobiles in 1987 and on trucks in 1988.

The effectiveness of the Canadian program and the results of U.S. control measures are monitored by measuring the quality of precipitation and of air in the Canadian Air and Precipitation Monitoring Network (CAPMoN), and by predicting the long-term response of ecosystems using specially developed computer models. The Canadian control program aims to reduce wet deposition of sulphate to lower than 20 kilograms/hectare/year, a target designed to protect moderately sensitive freshwater systems.
The Science Assessment is part of an effort by the Federal/Provincial National Air Issues Coordinating Committee to derive a strategy for the management of acidifying emissions in the post-2000 era. This strategy

will be discussed in the next year and will trigger a critical review of the existing research program. The Science Assessment that is underway will probably point to further areas where uncertainties preclude definitive statements to certain questions. In addition, the Assessment will point to other policy-related questions and clarifications.

[For description of present projects see Section 2.1]

2.0.2 HAZARDOUS AIR POLLUTANTS

In recent years, the role of the atmosphere as a pathway for toxic chemicals to remote areas of the globe has become widely recognized. With the appearance of industrial chemicals such as polychlorinated biphenyls (PCBs) in the Arctic and Antarctic, scientists began to examine this transport from "source" regions to "sink" regions. Several international efforts are underway to identify, measure and trace airborne toxics, to understand the processes that influence them, and to establish safe levels for them. Canada has played a pioneering role in defining the toxics issue and in pursuing solutions internationally.

The Great Lakes Water Quality Agreement was signed by Canada and the United States in 1972. Even though the major concern was the level of phosphorous in the Great Lakes, researchers detected the presence of other toxic chemicals in the Great Lakes, including substances such as PCBs and toxaphene that had been banned in the area. It is estimated that 90% of the PCBs in Lake Superior entered via the atmosphere. In 1987, the Great Lakes Water Quality Agreement was amended with Annex 15 to address air. Under this Agreement, the Branch is responsible for determining the concentrations of air toxics entering the Great Lakes basin on the Canadian side of the border.

A program has been initiated to determine levels and sources of toxic chemicals in the Arctic. Presence of toxics in arctic mammals is of particular concern since the diet of many northern communities consists mainly of fish and sea mammals Assessment of the toxic effects of anthropogenic organic substances is continuing through monitoring stations at Tagish in the Yukon, and at Alert, N.W.T.

Another thrust of the Branch is to develop environmental emergency response models for assessing the immediate effects of accidental releases of toxic chemicals into the atmosphere. For this work, the Branch has been recognized internationally by the World Meteorological Organization. In an emergency event, when chemical spills release highly toxic pollutants into the atmosphere, it is critical that decision-makers be able to respond quickly and effectively. Branch scientists developed a modelling package called the Air Quality Package for Environmental Emergencies (AQPAC) which gives within minutes estimates of air concentration in three-dimensional space. Also hemispheric and global tracer models have been developed which can analyse and predict the environmental effects of major accidental releases of radioactive or toxic materials into the atmosphere.

To estimate the sources of pollution in the Arctic and the Great Lakes, researchers are in the process of assembling global emissions inventories. The inventory development work is facilitated by the Branch's participation in the Global Emission Inventory Activities under the International Global Atmospheric Chemistry Program and the United Nations Economic Commission for Europe's Task Force on Emissions Inventories. To provide emissions inventory data the Canadian Global Emissions Inventory Centre has been established.

Pesticides have been an effective tool for forestry and agriculture management. However, the benefits from spraying are offset to some degree by the unintended harm pesticides can cause to non-target plants and animals. Many pesticides have found their way into ecosystems which are remote from areas of application, and, depending on the pesticide, can bio-accumulate to adversely affect the ecosystem. Over the last decade, Branch specialists have collaborated with other North American researchers to assess the fate of aerially-applied pesticides. Results have culminated in a new spraying technique that is just as effective, yet uses up to 50% less pesticide.

[For description of present projects see Section 2.2]

2.0.3 TROPOSPHERIC OZONE

Photochemical smog is formed when nitrogen oxides (NOx) and volatile organic compounds (VOCs) react in the presence of sunlight. NOx are released from the burning of fossil fuels in automobiles, power plants and factories, whereas VOCs are emitted in gasoline fumes, and in the evaporation of solvents like those used for dry cleaning. There are also important natural sources of VOCs, such as forests. Ground-level or tropospheric ozone, distinct from the protective ozone layer in the stratosphere, is the primary end product of the complex reactions between NOx and VOCs, and is a major component of smog.

Ozone is hazardous to human health showing effects such as coughing, discomfort and decreased lung capacity. Some studies suggest that over the long-term, exposure to ozone may lead to increased susceptibility to respiratory illnesses, and premature aging of the lungs. Ozone also damages vegetation, thereby lowering crop productivity. In order to protect human health and vegetation, Canada has set its maximum acceptable level of ozone at an average of 82 parts per billion (ppb) for one hour. However, over the period 1984-91, this standard was exceeded at least once in almost very major Canadian city. In 1988, the Canadian Council of Ministers for the Environment set up the NOx/VOC Management Plan to resolve Canada's ozone problem by the year 2005 and identified three areas in Canada that are particularly affected by smog: the Lower Fraser Valley in B.C., the Windsor-Quebec City Corridor and the Southern Atlantic Region on the east coast of Canada.

Until recently, smog was seen as only a city problem. However, smog created in cities can be transported downwind on a regional scale, just like acid rain. In the Lower Fraser Valley smog is mostly locally generated, while in the Windsor-Quebec City Corridor, and in the Southern Atlantic Region, distant sources in Canada and the U.S. are important contributors.

The Branch is working with other federal, provincial and municipal agencies to ensure that adequate measurements are made across Canada to provide an accurate scientific basis for the development and, ultimately, the evaluation of ground-level ozone control strategies. Measurements needed fall into three categories: nitrogen oxides (NOx); volatile organic compounds (VOCs); and ground-level ozone. NOx and VOCs are precursors of ozone. Both must be present for the continued generation of ground-level ozone. At present, ozone is measured at eight rural sites in the Canadian Air and Precipitation Monitoring Network (CAPMoN), using an ultraviolet-absorption instrument that provides readings every minute.

This program furthers our understanding of the photochemical oxidants problem in Canada, and provides a sound scientific basis for the next phase of NOx/VOC Management Plan emission control measures. To prepare for the 1996 NOx/VOC Assessment, three Work Groups in the Science Program have completed and sent for peer review their reports, and the remaining four Work Group reports are very close to completion. Work had also started on the overall Synthesis/Executive Summary report.

Related to the assessment, major advances were made in model development and evaluation, and their application to emission control scenarios. Phase 1 of the evaluation of the regional oxidant models for eastern North America, using data from EMEFS (Eulerian Model Evaluation Field Study), was completed, as was the first phase of the Lower Fraser Valley model evaluation. Emission control scenarios to which the models would be applied were finalised, in consultation with the Air Issues Branch, and were run in order to evaluate the impact of these scenarios on ozone concentrations in the three problem areas of Canada. The models were also used to evaluate the impact of such actions as the Phase I NOx/VOC Management Plan controls, and the NOx and VOC controls in the Ozone Transport Region of the eastern United States.

In the area of measurements, the Guidelines Document and Implementation Plan for the national monitoring program were completed, and advances were made in a number of research-grade techniques for monitoring ozone precursors and other products of photochemical reactions. A considerable effort was devoted as well to data analysis, especially the implications of the data available to date on long-term trends, ozone-precursor relationships and local as compared to long-range transport. Monitoring continued for ozone and some of its precursors and co-products at Mount Sutton and several CAPMoN sites.

There were significant developments in the area of international co-operation on tropospheric ozone research. On behalf of the NOx/VOC Management Plan's Science Program, the Atmospheric Environment Service signed onto the charter of NARSTO (North American Research Strategy for Tropospheric Ozone) in November 1995. Plans were developed for a major Canadian contribution to NARSTO in 1996 - a field study called NARSTO-CE (Canada East) in the Windsor-Quebec Corridor/Southern Atlantic Region area - to be co-ordinated with the corresponding NARSTO-Northeast field study in the United States.

[For description of present projects see Section 2.3]

2.0.4 **STRATOSPHERIC OZONE**

The ozone layer is a protective covering located in the stratosphere between 15 and 40 km above the earth. In the 1970s, scientists began to suspect that certain human activities might be harming the ozone layer. It was realized in 1975 that chlorofluorocarbons (CFCs), used as coolants for refrigerators and air conditioners, were destroying stratospheric ozone. CFCs are extremely stable, remaining in the atmosphere for about 75-110 years. They break down only under exposure to the harsh radiation of the upper atmosphere, which causes them to yield chlorine. Just one molecule of chlorine released from CFCs can destroy up to one million molecules of ozone.

Measurements of ozone show that ozone depletion is indeed occurring. Above Toronto, the ozone layer has thinned by 4-5% since 1980. The most severe loss, however, is in the Antarctic, where there has been a 50% decrease in ozone levels during each October since the mid-1970s. Studies of the Antarctic "hole" have shown that the ozone is being destroyed by chlorine. Researchers are determining whether the depletion of the ozone layer, which has reached catastrophic proportions in Antarctica, will occur to the same degree over the Canadian Arctic. Sunlight and chemical processes similar to those that cause the ozone "hole" over the Antarctic each year are believed to cause ozone destruction in the Arctic vortex, a continent-sized region of cold air. The ozone loss is less severe in the Arctic because its vortex is not maintained during the sunlight period for as long as in the Antarctic.

The depletion of stratospheric ozone has two important environmental consequences. Firstly, the ozone layer absorbs much of the sun's ultraviolet-B (UV-B) radiation, which would otherwise reach the ground and severely damage plant and animal life. As the ozone layer is depleted, more UV-B gets through to the earth's surface and could result in increased levels of skin cancer and in reduced crop yields. Secondly, ozone plays a role in regulating the flow of heat through the atmosphere by absorbing the sun's radiation.

Under the Montreal Protocol of 1987, over 50 nations, including Canada, are moving to protect the ozone layer by phasing out the use of CFCs. However, CFCs already in the atmosphere will continue to deplete the ozone layer for several decades. Researchers are investigating the processes causing short and long-term variations in the ozone layer, the levels of UV-B reaching the earth's surface, and the changes in atmospheric radiation. Measurements and studies take place across Canada, as well as from space, aboard the U.S. space shuttles.

Canadian ozone research had its start in the 1930s with studies on the temperature structure of the stratosphere. Currently, there are 12 sites measuring total ozone. In the 1980s, Branch scientists developed the Automated Brewer Ozone Spectrophotometer, produced by Canadian industry, which has proven to be the world's most accurate ozone-measuring device. It is now operated in 23 countries. The Branch plays a leading role in the Global Ozone Observing System (GO_3OS) by managing the World Ozone Data Centre (WO_3DC) which now contains over 35 years of ozone data from GO_3OS stations around the world.

Using space and aircraft-based instruments, Branch scientists have made pioneering contributions to the knowledge of the structure and composition of the atmosphere. In 1984, experiments to measure ozone and ozone-related compounds were made from the U.S. Space Shuttle by Dr. Marc Garneau, the first Canadian to fly in space. The experiment, called the Sun Photometer Earth Atmosphere Measurement (SPEAM-1), used instruments developed and constructed by Branch staff. The experience gained making the SPEAM-1 hardware, coupled with the analysis of Garneau's results, contributed to the development of the more sophisticated instrumentation, SPEAM-2, which flew on the Space Shuttle with astronaut Steve Maclean in October 1992.

Although radiation measurements have been made for decades, little is known about the variability of the global energy budget from day-to-day and season-to-season, or the effects of this variability on climate. At the Branch's National Atmospheric Radiation Centre (NARC), ground-based measurements are taken continuously using sophisticated equipment. These data are used along with satellite measurements to develop radiation budgets. NARC is linked to the World Radiation Centre in Davos, Switzerland, which maintains the world standard group of radiation instruments for the World Meteorological Organization (WMO). This linkage ensures that measurements made in Canada are comparable with similar measurements made throughout the world. Every five years, Branch scientists meet with other researchers to compare instruments with the world standard group.

[For description of present projects see Section 2.4]

2.0.5 CLIMATE CHANGE

The climate on earth is ideally, and perhaps, uniquely suited to foster life due to the presence in the atmosphere of several gases, called "greenhouse gases", which form an insulating blanket around the planet. Greenhouse gases are transparent to the sunlight entering the atmosphere (shortwave radiation). However, they absorb and re-emit much of the outgoing longwave radiation from the earth's surface thus trapping in heat like the glass of a greenhouse. This "greenhouse effect" occurs naturally and is essential to the maintenance of a liveable climate on earth.

Over the last few generations, human activities have increased the concentration of greenhouse gases in the atmosphere to unprecedented levels, leading scientists to believe that an impact on climate is imminent. Fossil fuel burning and deforestation have both caused significant increases in the amount of carbon dioxide in the atmosphere. In the last 130 years, the concentration of carbon dioxide has risen by more than 25%. At the current rate of increase, it will double within a century. Methane, after having remained relatively constant for more than 10,000 years, has doubled in its concentration over the last century. With the present rate of increase of greenhouse gases, the surface temperature on earth could rise by as much as 3 °C by the year 2100.

The overall objective of the Branch's Climate program is to contribute to the understanding of greenhouse gases and aerosols - their trends, budgets and role in climate change - by carrying out measurements, modelling and process studies with a Canadian focus, and by interfacing with other major international programs. Resources were directed primarily at supporting measurements of greenhouse gases and aerosols, with a relatively smaller amount available for modelling.

Canada began monitoring carbon dioxide in 1969 at Ocean Station Papa in the north-east Pacific Ocean. There are now three monitoring stations in the program: at Alert in the high Arctic, Estevan Point, B.C. and Sable Island, N.S. By operating these remote stations, where background levels of carbon dioxide can be measured without the interference of local sources, Canada makes an important contribution to the international effort to determine global greenhouse gas trends. From 1975 to 1991, the carbon dioxide level at Sable Island increased from 333 to 358 parts per million (ppm), and at Alert from 332 to 357 ppm. Additional measurements related to atmospheric change (ozone, peroxyacetyl nitrate, aerosol chemistry and physics) are also measured at Alert and Fraserdale.

A field study was carried out in the Experimental Lakes Area of Ontario to assess the impact of biogenic emissions on climate via sulphate aerosol formation. A stable isotope mass spectrometer system was acquired and development work commenced on analysis of various stable isotopes, including several of importance to climate change.

In the carbon cycle modelling area, work commenced on the coupling of a 3-dimensional GCM (global circulation model) to a global mixed layer ocean model and land carbon cycle model. Fifty years of simulation of the ocean model were run on a supercomputer in a collaborative project with Tohoku University in Japan. Significant advances were also made in the incorporation of aerosol processes as an active element in climate modelling.

[For description of present projects see Section 2.5]

2.1 ACID DEPOSITION

2.1.1 ADOM Applications

- D. McKay, S. Venkatesh, M. Moran, J. Brook and B. Pabla

The AES Acid Deposition and Oxidant Model (ADOM) is a three-dimensional, regional-scale, episodic comprehensive Eulerian transport/chemistry model. As part of the modelling effort in support of the 1996 Acid Deposition Assessment report, ADOM was used to predict future-year annual sulphate (SO_4) wet deposition and ambient air concentration fields for four different sulphur dioxide (SO_2) emissions scenarios.

The first three scenarios corresponded to different stages in the implementation of current Canadian and U.S. acid-deposition legislation up to the year 2010. The fourth scenario considered the impact of further SO_2 emission reductions post-2010.

ADOM used to predict SO_4 wet deposition and ambient air concentration fields

Changes in SO_2 emissions were implemented in the ADOM emissions input files at the level of individual sources such as smelters, coal-fired power plants and major industrial facilities. Calculation of annual fields for each scenario was achieved by aggregating the results from 33 short-term episode simulations. Additional emissions-scenario simulations with ADOM in support of policy development are planned, including the impact of nitrogen oxides emission reductions.

Trajectories were computed for researchers in the Branch, in the DOE Regions and a few universities around the world. Trajectory computational data was also marketed to countries such as the Czech Republic, Sweden and England.

2.1.2 Modellers' 1990 Emission Inventory

- D. McKay, S. Venkatesh, M. Moran, B. Pabla and C. Sobkowicz

The most important input data set for any air-quality model is emissions information. In recent years, AES regional air-quality modellers have relied on the 1985 NAPAP modellers' emissions inventory. However, as of 1995, new national annual anthropogenic emissions inventories for 1990 became available for both Canada and the U.S.

A major data processing effort is required in order to convert an annual emissions inventory to a form usable by air-quality modellers. Emissions in an annual inventory are available only for a handful of so-called criteria air pollutants by province or county on an annual basis. Modellers require an emissions inventory that has the criteria air pollutants chemically speciated to the primary pollutant species considered by their models, spatially disaggregated to the horizontal and vertical grid used by their models, and temporally disaggregated so that seasonal, day-of-the-week and diurnal emission variations are represented. Such a conversion requires an advanced emissions processing system.

A contract was let to ORTECH in 1995 to modify an existing, public-domain urban-scale emissions processing system named EPS-2 to produce regional-scale air-quality model emissions files. EPS-2 is part of the U.S. EPA's Urban Airshed Model program suite. Four types of source -- point, area, mobile and biogenic -- must be considered. Deliverables will include a working version of the modified EPS-2 software package, to be called CEPS-1 (for Canadian Emissions Processing System, Version 1), and emissions files. CEPS-1 will constitute a major step forward in AES's capability to produce regional emissions files, and opens the door to the preparation of real-world emissions scenarios incorporating sector-specific controls.

CEPS-1 will be a major step forward in AES's capability to produce regional emissions files

2.1.3 Integrated Assessment Model

- G. Fenech, M. Moran, M. Olson, K. Puckett and D. Whelpdale

Over the past twenty years, a variety of mathematical models have been developed in Canada and elsewhere to simulate the long-range transport and deposition, and subsequent impacts of acidifying pollutants. These various models have been successfully applied within individual disciplines. However, approaching the acid deposition problem from a policy perspective requires that control costs and damage costs be considered for various emission scenarios, and this requirement in turn demands that the entire acid deposition system be modelled as a whole from emissions to aquatic, forest, agricultural, visibility, wildlife, materials and health effects. A natural approach is to link available component models across disciplines within an overall integrating framework.

AES has collaborated with the National Water Research Institute in Burlington, developers of the PC/Window-based environmental information system RAISON, to produce an Integrated Assessment Model (IAM) capable of assessing the ecological impact at selected receptor sites in eastern North America of sulphur dioxide (SO_2) emissions changes across North America. The IAM now includes an SO_2 emissions inventory, a source-receptor module, an aquatic-chemistry module, and several waterfowl and fish effects modules. It can be run in either a scenario mode to predict the impact of SO_2 emissions changes on wet sulphate (SO_4) deposition or an optimization mode to predict the SO_2 emission changes required to achieve a desired change in wet SO_4 deposition levels.

The IAM will be used to help define the strategy for the management of acidifying emissions in Canada post-2000. Current plans call for the addition of other modules to the IAM, including a cost module to predict the costs of emissions changes and several other effects modules.

IAM capable of assessing ecological impact at selected receptor sites in eastern North America

2.1.4 Visibility Assessment
- R.M. Hoff, L. Guise-Bagley and M. Moran

Canada/U.S. Accord requirements address atmospheric visibility as a supplementary air quality criterion for sulphate reduction and transboundary transport. Since 1992, visibility has been assessed nationally using a combination of synoptic station observer reports (1951-1990 period), measurements at four sites in B.C., Alberta, Ontario and New Brunswick, and studies of the aerosol optical properties. These results have been included as part of the 1996 Acid Rain Assessment. Clearly, visibility has improved since the 1950s and 1960s, and there is some indication that current sulphur controls may be improving visibility further. Measurement data show that the median visibility is over 100km at the Alberta and New Brunswick stations, but only around 50km in rural southern Ontario.

Prevailing visibility in eastern Canada is largely controlled by amount of sulphate in air

In addition, predictive studies are now being undertaken to assess the change in prevailing visibility due to changes in sulphate emissions from the Canadian and U.S. Sulphur control protocols. These results are being included as a post-processing algorithm for the ADOM aggregation scheme used in the 1996 Assessment. Computer-generated scenes have been completed which show the response of the atmosphere to reductions in aerosol which correspond to the scenarios used in the Assessment.

As sulphate decreases due to the Acid Rain controls, we expect visibility to improve by 2010

Model runs have been undertaken using the Danish ACDEP model for the Fraser Valley airshed. These analyses show that the measured aerosol loads in the eastern Fraser Valley during the REVEAL I and REVEAL II study periods are consistent with the known sources of sulphur and nitrogen in the valley. Important is the identification of refinery sources south of the Canadian border in contributing to impaired visibility in the eastern Fraser Valley (a conclusion consistent with the 1993 Pacific'93 lidar results). This project was possible due to collaboration with K. Macdonald (DOE Prairie and Western Region), J.I.Campbell (U. Guelph), W. Malm (U.S. National Parks Service) and S. Pryor (U. Indiana).

2.1.5 CAPMoN Field Operations
- D. MacTavish, W. Kobelka, D. Ord and A. Gaudenzi

The Canadian Air and Precipitation Monitoring Network (CAPMoN) operated 11 air filter pack measurement sites and reduced the number of precipitation chemistry sites from 22 to 20. On the last day of 1995 Island Lake and McCreary, Manitoba, precipitation chemistry monitoring sites were closed. National operations were co-ordinated and supported from Downsview and managed by DOE Regional Staff. Regular calibration/inspector program was maintained at all sites, network wide. Nova Scotia Environment established a precipitation chemistry monitoring site at Sherbrooke, Nova Scotia, as a co-operative effort with the Branch.

CAPMoN consists 20 precipitation chemistry sites with 11 having air filter pack systems

2.1.6 CAPMoN National Laboratory
- D. MacTavish, N. Lance, R. Braga, B. Kessler and B. Kiely

Chemical analyses and the compiling of CAPMoN laboratory data sets for the 1995 network samples were completed. This included the analysis of over 15,000 filters and 7,500 precipitation samples, involving more than 154,000 chemical determinations.

During the year, CAPMoN laboratory completed more than 154,000 chemical determinations

Laboratory credibility was maintained by continued successful participation in international intercomparison studies including Environment Canada's Long Range Transport of Air Pollutants Intercomparison, the WMO-GAW's Laboratory Intercomparison, the United States Geological Survey Intercomparison, and the Norwegian

Institute for Air Research's European Measurement and Evaluation Program Laboratory Round Robin Study.

2.1.7 CAPMoN QA and Data Management

- R. Vet, M. Shaw, S. Iqbal, S. Ahmed and W. Sukloff

The CAPMoN air, precipitation and ozone data underwent quality control/quality assurance for the period September 1994 to September 1995. The balance of the 1995 data will be finalized in June 1996. A new data management and quality control system based on the Research Data Management and Quality Control (RDMQ) system was implemented for the CAPMoN ozone data. Work continued on applying the same system to CAPMoN air filter pack data.

Performance audits were carried out at all CAPMoN sites where precipitation, air and ozone measurements are collocated, and an audit report was produced. Finalized data were transferred to the National Atmospheric Chemistry Data Base and the National Air Pollution Surveillance Network Data Base.

2.1.8 NAtChem Database

- R. Vet, C.U. Ro, D. Ord and B. Sukloff

In 1995 the National Atmospheric Chemistry Data Base (NAtChem) activity focused on compiling data reports and presenting these analyses. The NAtChem database was successfully updated to 1993. It now includes complete Canadian, US NADP/NTN (National Atmospheric Deposition Program/National Trends Network) and CASTNET (Clean Air Status and Trends NETwork) data.

The NAtChem 1993 Annual Reports (NAtChem 1993 Annual Report; NAtChem 1980-94 Annual Reports: Acid Precipitation in Western and Eastern Canada; and NAtChem Annual Reports: CAPMoN 1983-1994) were distributed to provincial network co-ordinators, various data users and foreign countries.

The precipitation chemistry data were thoroughly analyzed to obtain long-term trends of acid deposition, to investigate the change of deposition patterns and to estimate the long range transport of air pollutants from US to Canada.

Precipitation chemistry data thoroughly analyzed to obtain long-term trends of acid deposition

NAtChem staff presented the 1993 Annual Report and data analysis results to the western provinces and to the Atlantic Regional office, and helped staff of the Nova Scotia Ministry of the Environment to establish its database management system. During the year, there were 58 data and analysis requests. Special analyses were completed for the 1996 Acid Rain Assessment and were included in Chapter 2: Atmospheric Science.

2.1.9 RDMQ System

- B. Sukloff and R. Vet

The Research Data Management and Quality Control (RDMQ) system provides a mechanism for recording information and presenting it in the form of expert advice. This "expert system" is easily accessible and provides continuity in the application of flags and comments during the quality control process. The entire data management and quality control process has resulted in a significant savings in resources required to perform these tasks. A reported entitled "RDMQ-Ozone Data Management and QC" was produced to document the system.

Expert system is easily accessible and provides continuity in the quality control process

This system is being used for the quality control of the CAPMoN precipitation data but the experience gained will be used to implement the system for the CAPMoN air quality data. RDMQ was also implemented for the Northern Contaminants Monitoring Network (NCMN) through Bovard Environmental who performs data management and quality control services.

RDMQ was implemented for the calibration procedures performed by the CO_2 monitoring network. The old system for calculating calibrations was written in the Paradox database language but this system had limitations in numerical precision, graphical presentation and speed. The new system, base on RDMQ, was written in the SAS programming language. It operates on a Unix server that runs the calibration calculations in a fraction of the time it took to run on the Paradox system. The interactive screens and reports in RDMQ have reduced the time required to produce a finalised set of calibrations.

In a related project, an inventory of environmental datasets in the Branch was produced. The inventory contains information about the project goals, elements measured, time coverage, measurement locations, data volume, data availability, contact person, etc. The report was presented to the Director, along with a set of recommendations for data management standards for the Branch.

2.1.10 Dry Deposition Velocity Over a Marine Surface

- A.K. Lo and L.-M. Zhang

The present study investigates the effect of humidity in the deposition layer adjacent to the air-water interface, the effect of broken water surface, and the effect of relative humidity in the turbulent transfer layer on the dry deposition velocity of particles over a marine surface.

Boundary layer parameters in the turbulent transfer layer within the constant flux layer were evaluated based on the modified direct method of Lo (1993). Effects of relative humidity on atmospheric stratification as well as on other boundary layer parameters were evaluated. Previous studies indicate particle growth arising from humidity and enhanced transfer processes due to broken water surface contribute significantly to deposition velocities of aerosol particles. It was also found that the humidity effect in the turbulent transfer layer on the dry deposition velocity cannot be omitted in low wind and mildly stable cases especially over a warm water surface.

Transfer processes due to broken water surfaces contribute to deposition velocities of aerosol particles

2.1.11 Mesoscale Boundary Layer Model Module

- A. K. Lo

This study further generalizes the direct method of Lo (1993) by removing the constraint of $z_{0h}=z_{0m}$ in the derivation of the relationship between stability, fluxes and turbulent transfer coefficients which is still being used in many meteorological and climate models.

The present study treats the general case that z_{0h} is not equal to z_{0m}. An analytic relationship for the stable case between the bulk Richardson number, Ri_b, and the Monin-Obukhov stability parameter has been successfully derived. For the unstable case, this relationship is expressed in the form of a non-linear transcendental equation which can be solved numerically using a proper initial value.

Other boundary layer flux parameters are evaluated using the direct method similar to that of Lo (1993). This direct method requires only a single level of atmospheric data coupled with the surface temperature, and has wide applications for the determination of boundary layer flux parameters both over a land and over a marine surface. In the case of a marine boundary layer study, the present method becomes most useful when conducting measurements over water. For this case, measurements are often limited to a single atmospheric level whether it is the aircraft data, the shipboard data or the more popularly used buoy data. Results have shown that errors introduced due to the use of $z_{0h}=z_{0m}$ for situations where z_{0h} is not equal to z_{0m} can be very significant.

Direct method requires only a single level of atmospheric data coupled with surface temperature

2.1.12 Trace Elements on Aerosols

- C. Matthias

Aerosols were analysed from high volume samplers located in Ontario to determine concentrations of trace elements, and to identify the type and location of the source. Data were collected at Burnt Island, Egbert and Point Petre. Monthly concentrations (box and whisker plots) and trends for up to 6 years were plotted for several elements, as well as for total organic carbon, total suspended particulate, sulphur dioxide and sulphate.

Enrichment analysis, factor analysis and positive matrix factorization offer possible explanations of source types. The use of back trajectories and a Potential Source Contribution Function (PSCF) analysis attempts to identify the source locations within North America of 34 elements. Preliminary results for Al, As, Br, Fe, Na, Sb and Se indicate that these methods for specifying source type and source location are questionable. The PSCF method is regarded as qualitative.

Methods for specifying source type and source location are questionable

2.1.13 Climatological Dispersion Model

- C. Matthias

The objective was to examine a numerical advection-dispersion model which calculates pollutant concentrations, fluxes and deposition on a long time scale (monthly to annual) with speed, accuracy and minimal data input. The time-dependent advection-diffusion equation was coded in explicit finite-difference form in spherical coordinates in 2 dimensions (latitude and longitude). There is a single layer at present in the vertical direction in which pollutants are assumed to be well mixed. The diffusion is driven by climatological meteorology gridded each 2.5 ° on a time scale as short as 1 month.

The regional version was tested using a 1985 sulphur dioxide (SO_2) source inventory for North America on a 1 degree grid. Using mean annual winds and precipitation, wet and dry deposition, and 1st order decay to sulphate, annual sulphate wet deposition to the surface was calculated and plotted. Results compared well to 1985 measured wet deposition of sulphate to eastern North America. The global version was tested using a 1980 global SO_2 source inventory on a 7.8 x 10°grid. Sulphate particle concentrations in the air near the surface compare well to those calculated by a 3-dimensional Lagrangian model with 4 vertical levels.

Results compare well to 1985 measured wet deposition of sulphate to eastern North America

2.1.14 Continuous Model of Aerosol in the Stratosphere

- A. Koziol-Gajdeczko and J. Pudykiewicz

Physical and chemical processes occurring in the stratosphere are of primary importance in the research dedicated to global atmospheric chemistry, as well as global climate modelling. Therefore, it is extremely important that these processes are well understood, and that the suitable numerical models are developed. This project involves the numerical modelling of the so called stratospheric aerosol layer which has been well known since 1961 when the pioneering measurements of stratospheric aerosol were performed by Junge. It was discovered then that the stratospheric aerosol is mainly composed of an aqueous solution of sulphuric acid in water. A great amount of both experimental and theoretical work has been done in the past twenty years to explain the mechanism of stratospheric aerosol formation. It is believed now that the aerosol layer is maintained by a periodical influx of sulphur dioxide (which later oxidizes to sulphuric acid) injected by volcanic eruptions. Based on the present state-of-the-art in the stratospheric aerosol research, a three-dimensional module of stratospheric aerosol and chemistry was formulated.

This model assumes that the stratospheric aerosol is composed of dry particles (Aitken nuclei of tropospheric origin), liquid homogeneous drops of aqueous sulphuric acid, and heterogeneous droplets composed of cores of solid matter surrounded by aqueous solution of sulphuric acid. In order to properly describe the behaviour of these cores, the additional quantities---the first and second central moments of the core distribution are modelled. The total number of the variables describing the aerosol to be integrated in time amounts then to five variables. Additionally, several chemical species involved in reactions leading to the oxidation of sulphur dioxide are also integrated. The aerosol particles undergo physical processes such as coagulation, nucleation, and condensation and evaporation of both water and sulphuric acid. Additionally, the aerosol particles are advected by a three-dimensional flow field.

The stratospheric aerosol models currently used by the modelling community are mainly discrete bin models. Our model is based on a continuous treatment of all the variables with a special attention paid to the mathematical correctness of numerical schemes. In particular, the calculation of coagulation rates are based on Gauss-Legendre quadratures and condensation/nucleation, and advection schemes are based on a positive advective algorithm.

Aerosol particles are advected by a three-dimensional flow field

2.2 HAZARDOUS AIR POLLUTANTS

2.2.1 Integrated Atmospheric Deposition Network

- R.M. Hoff, F.A. Froude, J. Woods, F. Maclean, B. Martin, B. Sukloff, K.A. Brice, K. Su, L. Liao, N. Alexandrou, M. Shoeib, T. Bidleman and W. Schroeder

As part of the responsibility under Annex 15 of the Great Lakes Water Quality Agreement, AES operates the Canadian stations in the Integrated Atmospheric Deposition Network (IADN). This program provides, on a biennial basis, loading estimates of IJC priority toxic chemicals to the Great Lakes.

Canadian sites in Ontario at Point Petre, Egbert and Burnt Island have been in operation since 1988. Samples are taken every 12 days in air for trace organics, TSP/TOC and trace elements. Meteorology at the sites is monitored on a continuous basis. The U.S. Environmental Protection Agency operates master stations on Lake Erie, Lake Michigan and Lake Huron as part of the IADN program. Over 15 other regional sites are included in the IADN co-operative program under the Canada/Ontario Agreement. Results of the monitoring are biennially reviewed and loading estimates are prepared for each of the five Great Lakes. Data through the 1993 monitoring year were reviewed and the assessment will be published.

Gas-transfer of organic chemicals to and from the lakes is largest component of air-water transfer

This project involved many scientists from other participating organizations: Bandemehr (U.S.E.P.A.), W.M.J. Strachan, (NWRI), M. Neilson and C.H. Chan (EHD/EC-OR), D. Orr (OMEE), S. Landsberger and S. Biegalski (U. Illinois), D. Muir (DFO, Winnipeg), D. Gatz, C. Sweet and K. Harlin (Illinois State Water Survey), D. Poster (NIST) and J. Baker (U. Maryland).

More research needed on the 'grasshopper effect'

2.2.2 Coplanar and Mono-ortho PCBs in Urban Air

- T. Bidleman and T. Harner

Several PCB congeners elicit toxic responses similar to those of polychlorinated dioxins and furans. Those of most concern are the "coplanar" (non-ortho) congeners 77, 81, 126 and 169, and the mono-ortho congeners 105, 114, 118, 123, 156, 167 and 189. A number of these are contaminants of Great Lakes fish and account for the major share of the dioxin-like toxic equivalents (TEQ) in biota and human milk. PCBs and other semivolatile compounds are present in air as vapours and sorbed to aerosols. Wet and dry deposition of particulate PCBs, especially the coarse particle fraction, is thought to contribute heavily to loadings to the Great Lakes near urban centres. This research is designed to test the hypothesis that coplanar and mono-ortho PCBs are preferentially sorbed to aerosols. Higher fractions on particles would lead to more efficient removal from the atmosphere by precipitation and dry deposition.

The project objectives are to develop analytical methods for coplanar and mono-ortho PCBs in air, to determine the levels of total PCBs in Chicago air, to compare the particle/gas distributions of PCBs having different numbers of ortho-substituted chlorines, and to compare the sorption of PCBs to other classes of aromatic compounds such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated naphthalenes (PCNs).

The study was supported by the U.S. Environmental Protection Agency and comprises of field and laboratory experiments carried out in 1988, 1989 and 1992-1995. Renee Falconer of Youngstown State University is collaborating on this project. Results of the 1988-89 measurements in Chicago and laboratory investigations of PCB sorption to urban aerosols have previously been published. This report summarizes recent results.

Air samples were collected at the Illinois Institute of Technology (Chicago) in February 1995, and analysed for PCBs and PCNs. The PAH data have not yet been finalized. Total PCBs (sum of 50 congeners) in Chicago air ranged from 140-610 pg/m^3 (mean = 350 pg/m^3). Average concentrations of coplanar and mono-ortho congeners were (pg/m^3): 77 = 0.42, 81 = 0.039, 126 = 0.063, 169 = 0.012, 105 = 3.3, 114 = 0.14, 118 = 8.6, 156 = 0.79. For comparison, two air samples were taken in March 1995 in North York, Ontario. These yielded the following values (pg/m^3): total PCBs = 502-543, 77 = 0.28-0.33, 81 = <0.020-0.026, 126 = 0.021-0.026, 169 = 0.005, 105 = 1.0-1.3, 114 = 0.08-0.13, 118 = 4.4-4.9, 156 = 0.14-0.21.

Total PCNs averaged 95 pg/m^3 in Chicago with a range of 24-179 pg/m^3, with one exceptionally high value of 470 pg/m^3. This was found on a day when the sampling site was downwind from a building that was being demolished and rubbish was being burned. A few of the PCNs are strongly bioaccumulating and have been assigned TEQ values. Concentrations of these congeners in Chicago were similar to or exceeded levels of the coplanar PCBs. Aside from measurements of PCNs near wire reclamation plants in the early 1980s, ours are the only reported values in ambient air.

A few of the PCNs are strongly bioaccumulating and have been assigned TEQ values

Particle/gas partition coefficients (K_p) were calculated for PCBs in Chicago air and related to the liquid-phase vapour pressure (p^o_L) of the congeners. Values of p^o_L within a homolog group decrease in the order multi-orthos > mono-orthos > coplanars. Thus the more toxic coplanar and mono-ortho PCBs should be enriched on airborne particles relative to the di- and tri-ortho congeners. This was found for both the Chicago and the North York samples. Increased sorption due to the lowering of vapour pressure is referred to as the "primary ortho-effect." In addition, a "secondary ortho-effect" enhances the sorption of coplanar PCBs over what would be expected from lower vapour pressure alone. This secondary effect was seen in log-log plots of K_p vs. p^o_L for both the Chicago and the North York samples, and also for the 1988-89 Chicago measurements.

The octanol/air partition coefficients (K_{oa}) is a promising alternate to p^o_L for describing the partitioning (absorption) of semivolatile compounds into organic liquid films on aerosols and vegetation. Values of K_{oa} for the PCBs and PAHs have been measured at -10 to +30°C, and log-log plots of K_{oa} vs. p^o_L showed that compounds of the same vapour pressure partitioned from air into octanol in the order: PAHs > coplanar and mono-ortho PCBs > multi-ortho PCBs. Sorption of PCBs to Chicago aerosols was adequately described by a single log-log relationship between K_p and K_{oa}, regardless of the ortho-chlorine substitution. Thus K_{oa} was able to account for the secondary ortho-effect which vapour pressure was unable to resolve. Preliminary measurements have been made at 20°C for the octanol-air partition coefficients of PCN congeners, and log K_p values for PCNs in Chicago were well correlated with K_{oa}.

Because of their high abundance relative to the coplanar PCBs and the fact that they are bioaccumulating and toxic, it is recommend that further investigations be conducted of PCNs in air, precipitation and biota of the Great Lakes. Sorption of coplanar PCBs to atmospheric particles is enhanced compared to other PCBs of the same homolog group. As a consequence, precipitation scavenging and particle dry deposition are likely to preferentially deliver the most toxic of the PCB congeners to the Great Lakes. The octanol-air partition coefficient appears to be a better parameter than vapour pressure for describing sorption of semivolatile compounds to urban aerosols.

2.2.3 Chlorinated Pesticides and the Great Lakes

- T. Bidleman, T. Harner, L. Jantunen and J. Wideman

Collaborators on this project were: Renee Falconer, Youngstown State University; William Parkhurst, Tennessee Valley Authority; Henry Alegria, University of South Carolina; Antonio Finizio, University of Molise; and Sunny Szeto, Agriculture and Agri-Food Canada.

Although most organochlorine (OC) pesticides have been banned in Canada and the U.S., they continue to be found in air and precipitation. Trajectory analysis of air sampling events at Egbert, Ontario, during 1989 showed that air currents arriving from the south carried elevated levels of OC pesticides, particularly DDT, toxaphene, chlordane and dieldrin. Sources of these compounds may include volatilization of soil residues and atmospheric transport of freshly applied material in countries where usage is still permitted, such as Mexico and Central America. This project was designed to investigate present-day sources of OC pesticides to the Great Lakes by measuring concentrations of airborne pesticides in suspected source regions as a comparison to those found at IADN (Integrated Atmospheric Deposition Network) stations, to determine the potential for agricultural soils in the U.S. to contribute OC pesticides to the atmosphere through volatilization, and to investigate the use of marker compounds to distinguish "old" (soil derived) and "new" (freshly applied) sources.

In August 1994, researchers started a project to measure atmospheric concentrations of OCs in the southern states and to examine agricultural soils for OCs. From August 1994 - January 1995 air samples were collected in Columbia, South Carolina. Mean concentrations of chlordane and toxaphene over the six-month period were 290 and 190 pg/m^3. By comparison, annual means for chlordane and toxaphene at Egbert in 1988-89 were 82 and 26 pg/m^3. The 1993 annual mean for chlordane at U.S. IADN stations was 29 pg/m^3.

Air sampling was initiated in January 1996 at the Tennessee Valley Authority (TVA) headquarters in Muscle Shoals, Alabama. Samples are collected twice monthly for most of the year and three times monthly during late spring and summer. Approximately 40 soil samples were obtained from cotton fields in the Muscle Shoals region and from agricultural research stations in central and southern Alabama. These will be analysed for toxaphene, DDT and other OC pesticides to determine the reservoir of pesticide available for volatilization.

A preliminary survey of airborne pesticides in Belize, Central America, was carried out in December 1995. Six samples were taken at an inland station and three at a coastal site. The mean concentrations at the inland location were (pg/m^3): DDTs = 1200, dieldrin = 1210, aldrin = 1180, chlordane = 91 and toxaphene = 45. Levels at the coastal site were: DDTs = 190, dieldrin = 45, aldrin = 4, chlordane = 54 and toxaphene = 26. By comparison, concentrations of DDTs, dieldrin and chlordane at U.S. IADN stations in 1993 averaged 26, 34 and 29 pg/m^3, respectively. The 1992 means at Pt. Petre were: 25 pg/m^3 DDTs and 23 pg/m^3 dieldrin. Toxaphene levels in Belize were only slightly higher than those found at Egbert during 1988-89 (26 pg/m^3) and below those measured in South Carolina during 1994 (190 pg/m^3). The Belize experiment will be repeated in August 1996 to compare winter-summer concentrations.

The use of pesticide enantiomers to trace emissions from soils was explored in the Fraser Valley, BC, and consisted of sampling air at heights of 5-130 cm above agricultural soils which were known to contain high levels of the chiral pesticides α-HCH, chlordane and heptachlor epoxide (HEPX). Concentrations of these chemicals decreased with height above the soil and the enantiomeric profiles in the soil were reflected in the overlying air.

To determine pesticide residues in the U.S. "Cornbelt", approximately 20 agricultural soils were sampled in eastern, central and western Ohio during 1995-96 and a protocol was established for analysis. Concentrations of DDTs in 10 of the soils examined so far were highly variable, ranging from <1 - 300 ng/g dry weight. Five soils from eastern Ohio showed a 15-25% depletion of (+)o,p'-DDT, whereas the o,p'-DDT in three others from western Ohio was racemic (ratio of the two enantiomers = 1.00). Chlordane and HEPX were non-racemic in all soils. Work will continue to analyse soil samples from other states in the Corn Belt (Illinois and Indiana) and to measure emissions of chiral pesticides from soil, similar to that carried out in the Fraser Valley.

High concentrations of DDTs, aldrin and dieldrin found in Belize suggest that these chemicals are still used in Central America and contribute to the atmospheric background over North America. Levels of toxaphene and chlordane were relatively low in Belize and much higher in South Carolina. Emissions of toxaphene and chlordane may be more related to old sources in the U.S. than to transport from south of the U.S. border. These conclusions are preliminary.

Organochlorine pesticides appear to originate from a variety of sources

Several chiral pesticides are selectively degraded in soils to yield residues which are non-racemic. Since pesticide enantiomers have identical physicochemical properties (such as vapour pressure and Henry's law constant), emissions from soil may be useful for distinguishing "old" and "new" source signatures. Chiral pesticides in the layer of air overlying agricultural fields in British Columbia showed the same enantiomeric profiles as residues in the soil. However, the degradation of chiral pesticides in soils varied among several farms in Ohio, and further work is required to determine whether enantiomer signatures can be used on a regional basis.

2.2.4 Toxaphene and HCHs in the Arctic

- T. Bidleman, L. Jantunen and L. Barrie

Various collaborators worked on this project: William Strachan, NWRI; Robie Macdonald, IOS; Barry Hargrave, DFO; and Renee Falconer, Youngstown State University.

Chlorobornanes (CHBs, e.g., toxaphene) are the dominant pesticide residues in fish and marine mammals in the Canadian Arctic and have been found in milk from women in arctic Québec. Yet CHBs remain the most poorly characterized organochlorines (OCs) with respect to levels in polar air and water, to physicochemical properties and to transformations in the environment. Hexachlorocyclohexanes (HCHs) are the most abundant OC pesticides in arctic air and water. More information is available on HCHs than for any other OC, making them the best candidates for investigating transport and exchange processes and for global-scale modelling.

Since 1992, this work has been supported by the Polar Continental Shelf Project and Northern Contaminants Program. The objective is to measure concentrations of CHBs and HCHs in arctic air and water and compare the air-sea gas exchange rates, to determine the physicochemical properties of CHBs that affect their atmospheric transport and deposition, and to characterize the changes in HCHs and CHBs that accompany transfer from air to water to the lower food chain.

Our research comprised three field studies: Resolute Bay in August 1992; an expedition to the Bering-Chukchi seas in August-September 1993 (BERPAC-93); and the Arctic Ocean Sections cruise across the polar cap in July-September 1994 (AOS-94). Air and water samples were collected for HCHs, CHBs and other OC pesticides, and the enantiomeric composition of α-HCH in air and water was determined.

An emphasis was to measure HCHs, CHBs and other OC pesticides in the Arctic Ocean and its regional seas. Surface water data were coupled with atmospheric concentrations to estimate air-sea gas fluxes. HCHs and CHBs concentrations in surface water of the Canada Basin above 80°N were 2-3 times higher than those in the Bering and Chukchi seas to the south. The pesticide pool under the ice cap may be a "ghost of the past" which will be slowly drained, largely through the Canadian Archipelago, on a time scale of decades.

Declining atmospheric concentrations of α-HCH have led to a reversal of the net gas exchange direction, from deposition in the 1980s to volatilization in the 1990s. The potential for volatilization is greatest in the Canada Basin because of the high concentrations of HCHs in water, but the actual amount of outgassing is limited by ice cover. It appears that the Arctic Ocean "breathes" largely through its regional seas and portions of the Eurasia Basin, where the ice cover is less extensive. Based on measurements from three field studies, HCHs showed a net volatilization loss from the Arctic Ocean of 26 tonnes per year in the early 1990s, compared to 165 tonnes per year deposition during the 1980s.

Enantioselective degradation of (-)α-HCH was found in the Bering and Chukchi seas, whereas (+)α-HCH was preferentially lost in the Canada Basin and the Greenland Sea. The opposite selectivity may be related to different microbial populations in these waters. The α-HCH in air sampled within 40 m of the ocean surface showed the same enantiomeric profile as the surface water. This provided direct evidence of revolatilization from surface water, since α-HCH from source regions is expected to be racemic.

Air-sea gas exchange accounts for over 80% of the atmospheric budget for HCHs and CHBs in the Arctic Ocean. Past loadings of these chemicals appear to have been greater in the past, and HCHs are now volatilizing from the Arctic Ocean and the Bering-Chukchi seas in response to declining atmospheric concentrations.

Outflow of polar water containing high concentrations of CHBs and HCHs will expose the biota in the Archipelago and Baffin Bay for years to come. The two enantiomers of α-HCH are degraded in seawater at different rates. Preferential breakdown of (+)α-HCH takes place in the Arctic Ocean, whereas the (-) enantiomer is selectively lost in the Bering-Chukchi seas. This is the first evidence that biological processes are responsible for removal of an OC pesticide from arctic waters. The enantiomeric signatures of α-HCH in surface water are reflected in the overlying air, providing direct evidence of sea-to-air transfer.

First evidence that biological processes responsible for removal of an OC pesticide from arctic waters

2.2.5 Organic Gas and Particle Sampler
- D.A. Lane

Taking the best attributes of both the Gas and Particle (GAP) sampler (developed by AES and ORTECH scientists) and the Integrated Organic Vapour and Particle Sampler (developed at Lawrence Berkeley National Laboratory -LBNL), the purpose was to produce a multi-annular diffusion denuder based sampler. This sampler would permit air sampling for a 24-hour period, direct elution of the denuder for the gas phase components, and accurate determination of the gas/particle partition ratios of atmospheric polycyclic aromatic hydrocarbons (PAHs).

In Phase I, GAP sampler denuders were modified to accept the XAD-4 coating developed at LBNL. The modified GAP sampler was used to collect atmospheric samples to assess the performance of the new denuders. It appears that naphthalene broke through the denuder since the apparent gas phase percentage is lower than that of higher molecular weight species. The gas phase percentages for phenanthrene and benz(a)anthracene could not be determined since the blank level exceeded that of the sample. The first problem can be corrected by slight design changes in the denuder geometry while the second can be corrected by better proofing of the blanks. These problems aside, the denuder side showed a good inverse correlation (except for naphthalene) between gas phase percentage and molecular weight. The conventional sampler shows virtually a constant gas phase percentage (>99%) for all compounds up to anthracene. This provides very strong evidence for blow-off from the conventional sampler. It is from evidence such as this that we are convinced that accurate gas/phase partition ratios for the PAC cannot be made with the conventional high volume sampler. The most accurate gas/particle partition determinations available today are produced by the diffusion denuder based samplers.

Collaborative research results in new air sampler

Based on the results of Phase I, Phase II was initiated and a new design for the new Integrated Organic Gas and Particle Sampler (IOGAPS) was developed. The annuli were decreased from 2 to 1 mm. Eight channels were used in the new denuder. Possanzini-type calculations show this new denuder to be capable of collecting greater than 99.9% of gas phase naphthalene at a temperature of -30 °C (suitable for arctic use). This is a significant improvement over the modified GAP sampler. The new sampler was build (under a Creative Research and Development Agreement (CRADA) granted to Dr. Gundel at LBNL) by University Research Glassware in North Carolina. The new prototype IOGAPS has been received and will undergo preliminary assessment in the next few months.

From this work, two inventions have been recorded:

- L.A. Gundel, **D.A. Lane** and A.T. Hodgson, Miniature integrated organic vapour/particle samplers with carbon-coated diffusion denuders, DOE record of Invention IB-1121 (April 1995).
- L.A. Gundel, **D.A. Lane** and A.T. Hodgson, Miniature integrated organic vapour/particle samplers with various adsorbent surfaces and denuder geometries, DOE Record of Invention IB-1122 (April 1995).

2.2.6 PAH Photochemistry

- D.A. Lane

In collaboration with S.S. Fielder (York University), S.J. Townsend (GENEXUS Inc.), N.J. Bunce, J. Zhu and L. Liu (University of Guelph), and B. Wiens and P. Pond (NOVAMANN (Ontario) Inc.), this project is to characterize the products of the photochemical reaction of naphthalene with the OH radical in the smog chamber which is located at York University.

In attempting to identify the primary products of the reaction of naphthalene with the OH radical, initial considerations have suggested that the 1- and 2-naphthols and the 1- and 2-nitronaphthalenes should be the primary products. This, however, appears not to be the case. Starting the reaction with 1-naphthol yields only one product (1,4-naphthoquinone) which is detectable by GC/MS. When starting the reaction with 2-naphthol or 1-nitronaphthalene, no products are detectable by GC/MS. Although the 2-naphthol was greatly reduced in concentration, indicating reaction, the 1-nitronaphthalene was not reduced, suggesting that it might be quite stable and, in fact, be an end product. The 1- and 2-naphthols, however, produce well over a dozen products, seen only by HPLC indicating that they are probably very polar species. It will require an HPLC/MS to identify these products as the reaction of naphthalene with the OH radical is much more complex than originally thought.

Experimental and theoretical studies reveal complexity of atmospheric reactions

Dr. Stan Townsend and Dr. Scott Fielder are assessing the mechanism suggested for the formation of one of the suspected products - 2-formylcinnamic acid. Several hundred 3-D colour images were produced showing the progress of the reaction. These images were transferred to video tape so that the reaction could be studied in detail. The video dramatically showed the value of the Graphic Electronic States Molecular Modelling program in understanding chemical reactions.

From the modelling, a more efficient route for the formation of the acid from the aldehyde was suggested. The model will be expanded to allow input of any starting molecule and reactants and to let the computer determine all of the likely products. Investigations are being undertaken to determine the feasibility of including thermodynamic parameters to add boundary conditions to the calculations. The goal is to have the model account for those products which comprise 99% of the product mass.

2.2.7 Transect '95

- W.H. Schroeder

Involvement in the European Measurement Campaign of Atmospheric Mercury Concentrations and Deposition: South - North Transect Experiment 1995 (Transect '95) was in support of the Germany - Canada Science & Technology Co-Operation Agreement. This project was co-funded by the Canadian government's Foreign Affairs and International Trade (FAIT) Department. The objective was to obtain high-quality information on mercury concentrations in air and in precipitation at several air quality measurement sites in Germany and in Sweden.

New, state-of-the-art, world-class Canadian mercury vapour analyzers were deployed in an intensive field measurement campaign to obtain up-to-date information on mercury concentrations in air and precipitation. The data set will be used at the GKSS Research Centre to test and evaluate the reliability of predictions for atmospheric mercury concentrations and wet deposition obtained from a modified ADOM (Acid Deposition & Oxidant Model) which includes a mercury chemistry module. This model was developed at GKSS in collaboration with the Ontario Ministry of the Environment and Energy.

New, state-of-the-art, Canadian mercury vapour analyzers deployed in intensive field study

Over a continuous two-week period (late June to early July), Tekran mercury vapour monitors were simultaneously operated at 2 sites in Germany (Neuglobsow and Zingst) and 2 sites in Sweden (Rörvik and Aspvreten). Precipitation samplers were also installed at all four sites but, due to unusually warm and very dry weather conditions that summer, little precipitation could be collected. Meteorological data for the study period is being provided to the modellers by the Finnish Meteorological Office. Data reduction, statistical treatment, plotting and exploratory interpretation of the atmospheric mercury data have been initiated.

The sophisticated numerical (Eulerian) atmospheric mercury model, which will be calibrated with the results from the Transect '95 field measurement campaign, is to be applied extensively in Europe, but could just as well be used in Canada or the U.S. for air pollution issues.

2.2.8 Mace Head Mercury Intercomparison

- W.H. Schroeder

Involvement in the Mace Head Mercury Intercomparison (International Field Intercomparison of Atmospheric Mercury Measurement Methods at Mace Head, Ireland) was supported by the Germany - Canada Science & Technology Co-Operation Agreement and was co-funded by the Canadian government's Foreign Affairs and International Trade (FAIT) Department.

This sampling and analytical methods intercomparison was organized by University College Galway, Ireland, and the GKSS Research Centre, Geesthacht, Germany. Measurement protocols included: total gaseous mercury (TGM), particulate-phase mercury (both conventional and denuder-based techniques), total mercury in precipitation, reactive mercury in precipitation, and methylmercury in precipitation. The Branch participated in determinations of TGM using a Tekran Mercury Vapour Analyzers. This gave the opportunity to compare results obtained with this instrument against results derived by traditional manual methods of sampling and analysis.

Scientists from twelve laboratories (8 from Europe and 4 from North America), actively pursuing environmental mercury research, assembled at Mace Head from September 10-15, 1995. The Mace Head Field Research Station, operated by the Atmospheric Physics Research Group at University College, Galway, is located on the west coast of Ireland, approximately 88 km west of Galway City, near Carna, County Galway (53°19' N; 9°54' W). The station has a clean air directional sector between 180° and 300° with open access to the North Atlantic Ocean. The weather was unusually co-operative (very warm and not too wet) for the duration of the field study.

> ***Scientists from twelve laboratories assembled at Mace Head in September 1995 for field study***

By December 1995, study participants had independently completed the analysis and interpretation of their finalized data sets. For AES and GKSS in particular, this study presented another timely opportunity to directly intercompare field measurement results for TGM produced by the same Tekran analyzers which were employed earlier that year in Germany and in Sweden during the Transect '95 European Measurement Campaign.

This international exercise is expected to lead to significant improvements in the quality, comparability and compatibility of environmental mercury measurement data, and will undoubtedly stimulate and accelerate standardization of sampling and analytical methodologies for prospective atmospheric mercury measurements.

2.2.9 Alert Mercury Measurements

- W.H. Schroeder

This project was supported through the Northern Contaminants Program/Arctic Environmental Strategy and the Arctic Monitoring and Assessment Program (AMAP), and was funded by DIAND. A baseline data set was obtained on the temporal variability of gaseous mercury species, and on atmospheric sources, pathways, processes, characteristics and removal mechanisms for airborne mercury in the Canadian High Arctic.

The only previously existing data set on atmospheric mercury concentrations in the Canadian Arctic was obtained in a series of exploratory 'mercury-in-ambient-air' measurements carried out at Alert, N.W.T., between August 1992 and August 1993. This historic data set was painstakingly obtained using manual sampling and analytical methodology to collect samples which were then flown to the AES laboratory for manual chemical analysis with Cold Vapour Atomic Fluorescence Spectrophotometry (CVAFS). A scientist at Oak Ridge National Laboratory in Tennessee is currently working with this data set to identify possible source regions of atmospheric mercury emissions likely to be contributing to the concentrations of this metal measured at Alert, using a numerical modelling technique called the "Potential Source Contribution Function" (PSCF) source-receptor model.

The suitability and reliability of a novel, sophisticated Canadian instrument -- the Tekran (Model 2537A) Mercury Vapour Analyzer – is being assessed for its application to making virtually continuous, automated TGM measurements in the Arctic environment. This instrument assessment was performed in three distinct phases. First, laboratory-based testing and evaluation obtained with the test instrument under various operating conditions and parameters were compared against the results of an AES reference. Second, an initial field trial was completed at a rural/remote location in North-Central Wisconsin in which the automated analyzer was intercompared with the traditional manual sampling and analytical methodology. Third, testing and evaluation, under harsh winter conditions, were undertaken in the Canadian Arctic at Alert, N.W.T.

Buoyed by the success of the 3-pronged evaluation effort conducted on the Tekran automated mercury vapour analyzer, atmospheric TGM measurements were initiated at Alert with this instrument in January 1995. The distinguishing feature of these on-going measurements, compared with the exploratory, manual 1992-1993 observations, is that the new data are characterized by a much higher temporal resolution (30-minute sampling times rather than weekly-integrated sampling intervals). The data acquired during 1995 are currently being processed and analyzed, both statistically and graphically.

With new system, data can be characterized by a much higher temporal resolution

This project has provided the first high-resolution time series of atmospheric mercury measurement data for the Canadian Arctic. This data set, in combination with results from other environmental measurement projects in the Arctic, will enable us to begin unravelling the complex atmospheric pathways/processes/ behaviour of mercury released into the environment in the highly industrialized nations of Europe, North America and Asia and in the emerging industrial economies of the rest of the world.

2.2.10 Aerial Application of Pesticides

- R.E. Mickle

In collaboration with the Canadian Forestry Service - Sault Ste. Marie (CFS-SSM), a series of research trials were undertaken to utilize improved spray strategies to maximize pesticide deposit and thereby reduce pesticide application rates. Two trials lead by CFS-SSM were completed in Manitoba, the first investigating the role of drop size on spray efficacy, and the second utilizing an AES enhanced spray strategy (spraying from the upwind wing only) in order to improve target deposit. Both experiments were supported with meteorological measurements using a tethersonde and spray parameter logging on-board the aircraft.

These data were used as input to spray fate models and the predicted deposits compared to in-field deposit measurements both on and off-target. Predicted deposit potential was correlated with GIS maps to investigate the potential movement of pesticide into off-target areas. A similar technique was employed in an operational spray in Newfoundland. Comparisons of predicted and measured deposition confirmed the technique which can be used to monitor operational spraying and to highlight the potential for environmental impact. Results of these two trials are available in reports published by CFS-SSM to the Spray Efficacy Research Group (SERG).

Comparisons confirm that technique can be used to monitor operational spraying

In early fall, AES again supported CFS-SSM in forestry herbicide trials in Northern Ontario geared to pesticide use reduction through improved drop size and volume spray strategies. Efficacy assessments will be completed by CFS-SSM this year. These trials completed the joint research projects with the Canadian Forestry Service.

In February, a Global Positioning System (GPS) Workshop, chaired by AES, was held in conjunction with the Canadian Aerial Applicators (CAA) Conference in Winnipeg. The workshop, sponsored by the provincial representatives of SERG, permitted the application industry to interface directly with suppliers to obtain a guidance system that would incorporate specific needs of the forestry industry. Results of relevant research programs were also presented in order to acquaint suppliers with research advances which could be incorporated into their systems. Highlighted were GIS expert management systems addressing sustainable forestry practices and real-time spray fate predictive models which could be used on-board aircraft to alert the pilots of potential environmental impact from off-site drift.

2.2.11 Setting Buffer Zones in Canada

- R.E Mickle

The generic approach to setting buffer zones in Canada received further use in the registration review of new pesticides in forestry. Utilizing industry recommended application strategies, the procedure was used to assess potential environmental impact and establish buffer zones as mitigative measures for environmental protection. The procedure has been accepted as an integral component in the registration of pesticides in Canada. Although used exclusively for aerial application at this time, the process will be extended into other use strategies including ground and air blast application in order to ensure uniformity in the Canadian registration process.

Procedure accepted as an integral component in the registration of pesticides in Canada

Discussions with the US-EPA, through the Pest Management Regulatory Agency (PMRA), are ongoing in order to harmonize registration procedures in both countries. A parallel registration procedure presented by the US Spray Drift Task Force to US-EPA will be evaluated by AES on behalf of PMRA and the Canadian Interdepartmental Task Force on Pesticide Drift. It is expected that the registration and regulation procedures of the two countries will be harmonized thereafter. At which time the generic approach will be transferred to PMRA.

2.2.12 Air Pollution Emergency Response Modelling

- S.M. Daggupaty and P. Cheung

Tests have been completed on the accuracy and sensitivity of the PC-AQPAC models. These results have been published in a recent conference proceedings. The PC-AQPAC model was demonstrated to research scientists from China, India and a researcher from UBC, Canada.

Training was given to the Ottawa Weather Office shift supervisors and meteorologists on the PC-AQPAC model, especially with regards to theory, special applications and validation results. On the average in a year, Ontario weather offices respond to about 30 pollution emergencies.

2.2.13 Mesoscale Boundary Layer Forecast Model

- S.M. Daggupaty and P. Cheung

Collaborative work with NYSDEC (New York State Department of Environmental Conservation) is continuing with the help of a graduate student working towards his Ph.D. Sam Daggupaty has been invited to be on his Ph.D. thesis committee by SUNYA (State University of New York at Albany). The model will be strengthen by modifying the physics on the marine boundary layer and urban heating effects, and by coupling a chemistry model for chemical pollution studies. The model has also been combined with a 3-D trajectory model. This trajectory model uses the variable acceleration algorithm which is more accurate and is an essential technique for studying transport of pollutants in the boundary.

As a part of the AECB (Atomic Energy of Canada Board) memorandum of agreement, the puff-trajectory dispersion module for diffusion and deposition of pollutants has been developed further. This will give an integrated real time air pollution prediction system on the mesoscale operating on a PC. Real time weather data input from the Regional Finite Element model will be interfaced with the prediction and puff-trajectory calculations. This predictive system for real time operational use will be streamlined for Pickering, Darlington and Bruce nuclear reactor sites.

A predictive system for real time operational use at nuclear reactor sites

2.2.14 Modelling Global Distribution of HCH

- J. Pudykiewicz

The global 3-dimensional hexachlorocyclohexane (HCH) transport model uses a system of advection-diffusion equations in spherical coordinates, and is executed using the data derived from the objective analysis system of the global meteorological model. The model is capable of moving toxic substances on a global scale using observed wind fields while allowing them to interact with the Earth's surface, clouds and precipitation. The objective is to model the spatial and temporal distribution of atmospheric g-HCH and a-HCH, and the fate of an annual pulse of fresh emissions on the global background. HCH was chosen as the compound of interest due to its wide use as a pesticide.

Model capable of moving toxic substances on a global scale using observed wind fields

The global 3-D HCH model was applied in order to establish the concentration of the HCH emitted into the atmosphere from the world's oceans. This modelling scenario is particularly important because the major part of HCH accumulated in the environment is stored in the ocean. The global distribution of HCH in the oceans was obtained by mapping experimental data onto a latitude-longitude grid. Finally, an interpolation algorithm using a polynomial weight function was used to generate the distribution of HCH on a global scale. After defining the state of HCH concentrations in surface reservoirs (land, snow and surface waters) as a function of location, the global tracer model was run for the time of one month. The source term of the advection-diffusion equation was derived using the forcing by the surface fluxes of HCH from the ocean to the atmosphere. The first run was performed with no fresh emissions of HCH. The results are representative to the situation prior to the release of a " fresh" annual pulse of HCH.

The ongoing research effort with the global HCH transport model will include running a global 3-D HCH model for 2 years (1992, 1993), performing an evaluation of this 2-year run using data obtained from measurements at Alert and other monitoring stations in the Arctic, enhancing information about snow and ice cover using satellite data, and continuing research in deriving a more accurate representation of HCH concentration in the oceans.

2.2.15 International Emissions Inventory

- Y.-F. Li

It is important to establish reliable emission inventories on a global scale in order to determine emission sources, to compile information on global usage of the highly toxic, persistent pesticides, to understand the atmospheric pathway, and to assess control options. The Canadian Global Emissions Inventory Centre (CGEIC) is participating in a number of international activities, such as the United Nations Economic Council of Europe's Task Force on Persistent Organic Pollutants and Heavy Metals, the UN ECE Expert Panel on Emissions, the Global Emissions Inventory Activity(GEIA) of the International Geosphere/Biosphere Program, and the United Nations Environment Programme (UNEP).

Hexachlorocyclohexane (HCH) is an organochlorine insecticide used throughout the world and is available in two formulations: technical HCH (a mixture of different isomers) and technical lindane (almost pure γ-HCH). Although only γ-HCH possesses insecticidal properties, all isomers are toxic. Usage of HCH and other organochlorine insecticides contributes to increased agricultural yield, protection of livestock, and the elimination of vector-transmitted disease. However, the global contamination caused by indiscriminate usage of HCH and other pesticides over the past four decades has been found to be ubiquitous and persistent in various environmental media and biota, even to remote areas like the North Pole through the long-range atmospheric transport. HCH (α- and γ-isomers) was the major organochlorine insecticide detected in arctic air and seawater. In Canadian Arctic snow, total HCH concentrations far exceed all other organochlorine compounds combined. As a result, the Arctic seas and nearby oceans serve as one of the significant sinks for toxic and bioaccumulative contaminants, and become a new source of HCH to the global environment. Evidence has shown that over 8,400t of HCH residues are present in the surface seawater of the North Pole region with about 500t of it going southward to the Atlantic Ocean every year through water currents.

In Arctic snow, total HCH concentrations exceed all other organochlorine compounds combined

The atmospheric modeling community is increasing its understanding of the occurrence and pathways of the contaminants. The modellers are required to differentiate between contributions from past use and from present sources, and to predict how these concentrations will change. These models require information on usage of the pollutants as a basis for estimating emissions.

The usage data for technical HCH and lindane have been collected for the years 1980 and 1990. Where data were missing, the nearest year's data were used. Sources of usage information were United Nation reports, government reports and scientific publications. Neither spatial nor temporal interpolation were made. In the near future, usage data will be used to translated into estimates of emissions. The total global usage for technical HCH was 40,000t in 1980 and 29,000t in 1990, and for lindane was 5,900t in 1980 and 4,000t in 1990. Based on these data, the global usage of both α-HCH and γ-HCH were estimated. The total usage of α-HCH was 28,000t in 1980 and 20,400t in 1990, while the total usage of γ-HCH was 11,900t in 1980 and 8,400t in 1990. The ratio of γ-HCH to α-HCH was 0.43 in 1980 and 0.41 in 1990. The usage data of both α-HCH and γ-HCH in 1980 and 1990 over a grid system with 1°x1° longitude/latitude resolution were compiled, and ready for use by environmental modellers.

Usage data of both α-HCH and γ-HCH compiled, and ready for use by environmental modellers

In 1990, India was major source of α-HCH, although the usage of α-HCH was almost phased out in the other area. The usage of γ-HCH in 1990 was in Europe, North America and South Asia. Some developed countries, such as Italy, France, United States and Canada, were among the leading lindane consuming countries.

2.2.16 Global Population Distribution

- Y.-F. Li

This project was initiated to increase the effectiveness of Canada's efforts in building global emissions inventories by integrating our work with that of the international community. Contributions are made to the United Nations Economic Council of Europe's Task Force on Persistent Organic Pollutants and Heavy Metals, the UN ECE Expert Panel on Emissions, the Global Emissions Inventory Activity (GEIA) of the International Geosphere/Biosphere Program, and the United Nations Environment Programme.

With the push towards sustainable development, there has been a growing demand for complete and accurate population data. Agenda 21 of the Rio conference, for example, stressed the need to formulate integrated national policies for environment and development which take into account demographic trends and factors. Population databases are forming the backbone of many important studies modelling the complex interactions between population growth and environmental degradation, predicting the effects of global climate change on humans, and assessing the risks of various hazards such as floods, air pollution and radiation. Detailed information on population size, growth and distribution is of fundamental importance to such efforts. Present data sets do not meet communities' requirements so a new global population data set is needed for the global scientific community. A population database has been provided that depicts the world-wide distribution of population. The database makes use of the most recent data available (1990) and gives a true apportionment for each grid cell as a percentage of a country's total population.

The global distribution of population for 1990 compiled, and ready for use

2.3 TROPOSPHERIC OZONE

2.3.1 CAPMoN Ozone and NOx Measurements

- D. MacTavish, S. Ahmed, W. Kobelka, D. Ord and A. Gaudenzi,

Continuous ozone measurements were maintained at 8 CAPMoN (Canadian Air & Precipitation Monitoring Network) air and precipitation monitoring sites. Quarterly inspections/calibrations were performed at all 8 sites. This year marked the second year of a intensive ozone audit program designed to ensure the accuracy and quality of CAPMoN's ozone data. Development work continues on the TECO model 42S NOx analyser which was converted to a NOy mode and installed at Egbert in July 1995. Operational protocols are still under development and the 1995 data will be released in 1996.

Continuous ozone measurements maintained at 8 of CAPMoN's sites

2.3.2 Optical Measurements of Gases and Aerosols

- R.M. Hoff, K.B. Strawbridge, M. Harwood, A. Sheppard, A. Macdonald, S.-M. Li and T. McElroy

This project investigated optical techniques for remote sensing of the atmosphere by using airborne lidar and a differential absorption lidar (DIAL) to measure aerosols and ozone in the troposphere. In the last three years, significant achievements have been made in the capability to make measurements both from the ground, from the air and from space. In regard to the latter, the Lidar In-space Technology Experiment (LITE), which flew on the space shuttle Discovery in September 1994, was part of this project. The airborne lidar system has been used in three experiments (Pacific '93, the 1994 LITE Validation, and the 1995 Radiation, Aerosols, and Clouds Experiments - RACE). The RACE experiment provided an opportunity to address climate as well as air quality issues by understanding the changes in the radiative properties of the atmosphere due to aerosols and clouds.

The DIAL system has undergone a redesign to replace the Raman shifting technology which was to have been a simple solution to generate the required two UV wavelengths for ozone profiling. Lack of robustness of the Raman cells proved to be a problem and the two ozone wavelengths will now be generated by separate frequency-doubled dye lasers. This will allow for movement of the UV frequencies to get solar blind operation in daylight and extended range at night.

LITE data are currently being analyzed with a focus on anthropogenically-derived aerosol plume signatures. Over 50 urban areas have been detected in the LITE data set, and these data show promise of allowing the assessment of sulphate loadings from a regional perspective.

LITE has shown ability to monitor aerosols globally

A follow-on mission to LITE, called the Pathfinder Instrument for Clouds and AerosolS Spaceborne Observation (PICASSO), is currently being proposed to NASA for flight in 2000-2002. This would be a two-year polar orbiting satellite designed to help assess climatic affects of aerosols and clouds, but also applicable to air quality assessment. A second co-operative project is the Ozone Research and Cloud Lidar Experiment (ORACLE), which is an instrument currently undergoing design by the Canadian Space Agency, NASA, and Optech Ltd.

Branch scientists have collaborated with M.P. McCormick, D. Winker, G. Kent, K. Powell, C. Hostetler, M. Osborn and E.V. Browell (all at NASA Langley), A. Dudelzak (CSA), A. Carswell and A. Ulitsky (Optech Ltd.), G. Isaac, R. Leaitch, K. Banic, H. Barker, I. Gultepe (ARMP), and L. Melfi (Science and Technology Corporation).

2.3.3 VOC Emissions from Vegetation

- J.D. Fuentes, H.H. Neumann, G. den Hartog, R.M. Staebler, J.M. Deary, J. Kovalick and A. Wiebe

The overall objective is to determine uncertainties in Canadian estimates of biogenic hydrocarbon emission inventories from deciduous forests by determining speciated hydrocarbon emissions from deciduous tree species, by establishing seasonal emission rates from single foliage elements and a forest canopy, and by comparing measured with modelled hydrocarbon estimates at the canopy level.

Investigators took field measurements of the microclimate, ambient hydrocarbons, canopy eddy correlation and gradient fluxes, atmospheric chemistry and leaf area distribution in the mixed deciduous forest at Borden, Ontario, during the 1995 growing season (April to October). Certain measurements, such as the microclimate and ambient hydrocarbon concentrations, were taken continuously, whereas highly specialized measurements, such as leaf and canopy hydrocarbon fluxes, were obtained only during certain periods. There were three intensive measurement campaigns: from May until June, measurements were taken to identify the onset and degree of hydrocarbon emissions from various tree species early in the growing season; in July, the seasonal peak hydrocarbon emissions were studied; and from August to September, the decline of hydrocarbon emissions during the leaf senescing period were examined. Ambient and flux measurements revealed the seasonality of hydrocarbon compounds from phytogenic origins in the atmospheric air over the mixed deciduous forest.

At present, both microclimate data and hydrocarbon emission factors are being used to test current modelling systems to provide estimates of hydrocarbon emissions from forests. Comparisons between modelled and measured isoprene emissions for Borden agree within 30%, with the models overestimating emissions. These comparisons apply to mid-growing-season conditions. Ambient biogenic hydrocarbons exhibited strong seasonal patterns. Almost non-detectable levels existed during the early and end of the growing season while maximum levels (12 ppb) occurred during the middle of the growing season. Based on the considerations of the lifetimes of the measured hydrocarbons (due to their chemical reactions with ozone and the hydroxyl radical), it was estimated that the compounds measured at Borden emanated within an area with a radius of 25 km upwind of the measurement site. Therefore, most of the biogenic chemical species measured at Borden were produced locally.

Comparisons between modelled and measured isoprene emissions within 30%

Extensive data sets comprising of natural and anthropogenic hydrocarbon compounds relate to the chemical species and levels of oxidant precursors in a rural area of southern Canada. Seasonal hydrocarbon emissions, at both the foliage and canopy levels, are available for a mixed deciduous forest. These data sets provide direct evidence that deciduous forests represent strong sources of biogenic hydrocarbons. Maximum isoprene fluxes measured at Borden exceeded 3 Tg (isoprene) per m^2 per second. These canopy emission rates, coupled with prevailing atmospheric turbulence, can give rise to ambient mixing ratios of 10 ppb immediately above the canopy. These atmospheric levels of hydrocarbons, if introduced in environments rich in nitrogen oxide sources, can be capable of enhancing ozone formation. Therefore, photochemical modelling studies must be conducted to ascertain the contributions of biogenic hydrocarbons to the overall oxidant formation in the ozone-affected areas of southern Canada. The onset of hydrocarbon (isoprene) emissions starts 2-4 weeks after leaf emergence.

Deciduous forests represent strong sources of biogenic hydrocarbons

One key accomplishment was the development of protocols to determine in situ measurements of isoprene and its oxidation products. These analytical capabilities are necessary to continue addressing the issue of the rapid chemistry of biogenic hydrocarbons in polluted atmospheres. Also, the gained knowledge can be incorporated in hydrocarbon emission algorithms. Uncertainties in current hydrocarbon emissions can be improved provided that the new information can be incorporated in the models presently employed to derive Canadian hydrocarbon emission inventories.

2.3.4 Continuous HNO_3 Measurement System

- S.-M. Li

A field-worthy prototype is now being tested and automated. A new method of detection has been deployed for specific detection of HNO_3 using a colour-forming agent which is nitrite ion specific. This is a vast improvement over the previous method which is less specific. The new method also improves system sensitivity. Under the best working condition, the system may detect 10 pptv of HNO_3, but it is expected that 50 pptv detection limit can be achieved for normal field operation, which is sufficient for most regional studies. The time resolution of the system is currently at about 1 minute but is unlikely to be improved much further.

System sensitivity may detect 10 pptv of HNO_3,but 50 pptv detection limit in the field

2.3.5 Gas Phase Chemistry Reaction Mechanism

- S.-M. Li and P. Makar

A chemical reaction mechanism has been formulated and is undergoing tests against available smog chamber results. The new mechanism incorporates the newest knowledge on the kinetics of the chemical reactions pertaining to regional atmospheres, including new reaction rate constants and their temperature dependencies, as well as new data on product yields. Effort is being made to improve the photolysis rate constant calculations, involving a new code for a radiative transfer model. This effort has spawned the development of a modelling tool, the Windows-based Chemical Reactions Box Modelling System, intended for the experiment-oriented research staff at AES.

2.3.6 Continuous Formaldehyde Monitor

- A.M. Macdonald and K. Asalian

An instrument for continuous monitoring of gaseous formaldehyde was assembled and tested. The method is that of Kelly and Fortune which is a fluorometric method utilizing the Hantzsch reaction. The detection level of approximately 0.1 ppbv was attained. It is appropriate for use at a ground site or on a pressurized aircraft and will be used during June-July 1996 as part of NARSTO-CE.

Continuous monitoring instrument capable of detection level of approximately 0.1 ppbv

2.3.7 Radiation Aerosols and Clouds Experiment

- A.M. Macdonald, S.-M. Li, K.G. Anlauf, M.F. Watt, K. Asalian, S. Sharma, H. Dryfhout and A. Tham

As part of the Radiation Aerosol and Clouds Experiment (RACE) of 12 August to 10 September 1995, chemistry measurements were made from the Twin Otter and Convair 580 aircraft platforms, and the Marine Atlantic ferry from Bar Harbour to Yarmouth. Goals for the chemistry measurements were to examine the biogenic sulphur cycle, to measure organic acids and carbonyl species in the gas-phase, particles and cloudwater, to characterize sulphate and nitrate in particles and cloudwater to measure hydrogen peroxide in cloudwater and gas phase, and to measure complimentary gas-phase species. Several good marine stratus cases were studied and the range of sampling conditions, from very clean to extremely polluted cases, will allow for goals to be achieved.

In addition to the traditional filter pack system for particle chemistry, particles were collected with a MOUDI impactor system which partitions the aerosol by size on to 12 separate filters per sample. Filters were analyzed in house and the chemical species can be correlated with particle size. MOUDI samples were collected both on the Convair and on the ferry.

For the first time, gas-phase carbonyl species were collected with a mist chamber. Unlike the mist for the organic acids, i.e., deionized water, the carbonyl species are collected and fixed immediately in a DNPH mist. These samples, along with filter and cloudwater samples, were analysed by liquid chromatography. Preliminary results look very good for cloudwater and particles.

For the first time, gas-phase carbonyl species collected with a mist chamber

The gas-phase H_2O_2 instrument was operated for the first time on the Convair. A highly polluted air mass was encountered on 9 September and H_2O_2 levels reached 4-5 ppbv while O_3 concentrations exceed 110 ppbv. Cloud water samples were also analysed for H_2O_2 in the field and concentrations exceeded 200 μm.

Air samples, collected on Tenax cartridges, were analysed for dimethyl sulphide (DMS). Samples were collected on all three platforms for a horizontal and vertical distribution of DMS over the Bay of Fundy and Gulf of Maine.

2.3.8 ARCTOC 1996

- R.M. Staebler, D. Toom, L.A. Barrie, S.-M. Li and J. Bottenheim

The ARCtic Tropospheric Ozone Chemistry project is the European equivalent of our Polar Sunrise Experiments. The second (and final) field component of the 2-year study was undertaken from March to May 1996 in Ny Clesund (79°N, 12°E) on the island of Spitsbergen, Norway, in collaboration with the University of Heidelberg and other institutes from Germany, Norway, Denmark, France and the UK. The objectives were to determine the physical size characteristics of the aerosols in arctic haze at Spitsbergen and develop relationships with the tropospheric ozone depletion process, to speciate inorganic gaseous and particulate bromine and nitrogen compounds to diagnose mechanisms for ozone destruction, and to compare the aspects of arctic tropospheric chemistry at Spitsbergen with those at Alert. Last year's study confirmed that chlorine and bromine catalysis cause the ozone loss, and showed evidence that the source of the reactive halogen species is direct liberation from sea-salt.

Study confirmed that chlorine and bromine catalysis cause ozone loss

2.3.9 NOx/VOC Modelling Program

- S. Venkatesh

The Canadian Smog Management Plan requires the use of oxidant models to examine the effects of NOx/VOC precursor emission controls on maximum ozone concentrations in non-attainment areas, i.e, areas where the ozone concentrations exceed the Canadian standard of 82 ppb. In eastern Canada, these areas are the Windsor-Quebec Corridor (WQC) and the Southern Atlantic Region (SAR). Models help in the understanding of the interaction between meteorological and chemical processes in a polluted atmosphere and ultimately improve our ability to forecast ozone episodes.

Models help in the understanding of the interaction between meteorological and chemical processes

A series of models were used to study the evolution of ozone episodes in the WQC/SAR regions. These included:

1. The Regional Oxidants Model (ROM 2.2) which is an U.S.E.P.A model;
2. The Acid Deposition and Oxidants Model (ADOM) combined with a small scale meteorological driver GESIMA;
3. The AES Lagrangian Oxidants Model (ALOM) which is a Lagrangian version of ADOM;
4. The ADOM model coupled with a newly developed meteorological driver MC2; and
5. The Chemical Tracer Model (A modified version of ADOM), with improved advection, coupled with the MC2 meteorological driver.

The above models were used in a detailed study of an ozone episode that occurred during August 1-6, 1988, affecting the north-eastern and for which extensive data were collected as part of the Eulerian Model Evaluation and Field Study (EMEFS). A detailed report on the assessment of these models along with the use of these models for evaluating various NOx/VOC control scenarios is under preparation. Additional information on two of the models can be found elsewhere in this document.

2.3.10 MC2/ADOM Modelling

- W. Gong, X. Lin, S. Menard, J. Bottenheim and B. Pabla

A MC2/ADOM modelling system was developed for the South Atlantic Region of Canada by coupling the two existing models (MC2 and ADOM). Nested runs were conducted using this modelling system for the simulation of regional oxidants during the EMEFS (Eulerian Model Evaluation Field Study) intensive period (August 1 - 6, 1988), as well as for a series of emission scenario tests. This work forms part of the NOx/VOC modelling working group report which will provide a basis for the NOx/VOC phase I assessment.

NOx/VOC modelling working group report will provide basis for NOx/VOC phase I assessment

The AES Lagrangian Oxidant Model (ALOM) was run for various control scenarios suggested by policy makers. The results will be included in the NOx/VOC assessment document.

2.3.11 AES NOx/VOC Model Enhancements

- J. Pudykiewicz

High concentrations of ozone in the lower part of the troposphere are considered as one of the most important issues of tropospheric chemistry. The chemical mechanisms of tropospheric ozone formation are complex, and highly variable meteorological conditions contribute additionally to difficulties in an accurate prediction of the ozone episodes. To understand the problem, to eventually improve the ability to predict the concentration of tropospheric ozone, and to formulate emission control strategies, a comprehensive model is applied that represents accurately the interaction between meteorological processes and chemical reactions.

To investigate the formation and evolution of tropospheric ozone, a semi-Lagrangian transport model with complex chemistry was developed that links an accurate advection algorithm with a comprehensive chemistry scheme. The Chemical Transport Model (CTM) was coupled to a semi-Lagrangian, non-hydrostatic, mesoscale meteorological model (MC2) that contains an extensive parameterization of physical processes (including a boundary layer scheme and clouds). The model included also an extensive data base of anthropogenic and biogenic emissions of nitrogen species, and volatile organic compounds.

The system of models was run for a time period of 6 days in order to generate a tropospheric ozone field during a smog episode observed in the Eastern part of North America in August 1988. The numerical simulation was performed on grids with resolution of 20 and 40 km with 25 vertical levels. The emissions inventory included point sources, surface biogenic sources, surface mobile sources and surface non-mobile sources. An evaluation of the model results against observations clearly indicates the ability of the system to simulate regional aspects of a tropospheric ozone episode. The general pattern of the ozone field observed at the surface is simulated realistically. The response of the ozone field to changing meteorological conditions is also consistent with experimental data. The model evaluation for the set of selected stations indicates that evaluation scores are high.

The model performance compares well to other model's results reported in the literature. The most important achievement is an elimination of errors associated with numerical diffusion and improvement of the representation of small scale structures of chemical fields. These facts could be attributed mostly to the non-oscillatory numerical scheme which guarantees preservation of monotonicity of transported variables and allows an accurate representation of the coupling between passive tracer advection and reactive chemical forcing of dependent variables. The important conclusion is therefore that the elimination of numerical errors is critical for an accurate simulation of ozone chemistry and a realistic representation of small scales structures of chemical fields.

Elimination of numerical errors is critical for an accurate simulation of ozone chemistry

2.3.12 Dry Deposition

- J. Padro, J.L. Walmsley and L. Zhang

The contribution of the chemical reactions of the NO-NO_2-O_3 triad and the NO surface emissions to the dry deposition of each of these species was investigated with a new model and with measurements over a local site. Results have indicated that chemical reactions can be important and should be included in dry deposition models involving these species. This new model was incorporated into a frozen version of the regional ADOM and integrations were carried out for a few days after equilibrium was established. Preliminary results indicate that the deposition can decrease by as much as 20% and the ambient O_3 concentrations can increase by as much as 10%. Similar results were obtained for NO_2. More ADOM runs are recommended before this model becomes a permanent feature of the operational ADOM. Such integrations will be facilitated in the near future when ADOM becomes available on a work station. External collaborators on the first part of this project were W.J. Massman and D.W. Stocker from the USA.

Including chemical reactions in a model could decrease deposition results by as much as 20%

2.4 STRATOSPHERIC OZONE

2.4.1 Arctic Stratospheric Ozone Research

- H. Fast

The winter campaign of field measurements at the Arctic Stratospheric Ozone observatory was designed to monitor, and to investigate stratospheric ozone and a variety of atmospheric constituents known to be involved in ozone depletion. The Eureka observatory is a primary component in the global Network for the Detection of Stratospheric Change (NDSC). Profile measurements were taken of ozone, temperature and aerosols.

This stratospheric research at Eureka was carried out in collaboration with the Meteorological Research Institute, the Communications Research Laboratory and the Solar Terrestrial Environment Laboratory in Japan, the University of Denver and Embry-Riddle Aeronautical University of the U.S.A. and the Institute of Space and Terrestrial Science, University of Saskatchewan and University of Western Ontario in Canada. The collaborating institutions have also contributed financially to the support of the observatory research projects.

Much of what has been learned so far at Eureka has been published, and some data are archived for accessible for further analysis by other scientists. The observations are in general agreement with the changes of ozone chemistry predicted by computer models. Analysis of measurements made at Eureka has helped to reveal the structure and properties of the polar vortex, specifically, gravity waves and the existence of laminae which suggests a mechanism for transport of air masses across the vortex boundary.

Measurements made at Eureka has helped to reveal the structure and properties of the polar vortex

2.4.2 International Ozone Depletion Study
- H. Fast, J. Davies, T. Mathews and J.J. Bellefleur

Ozonesonde launches at the six Canadian stations (Alert, Eureka, Resolute Bay, Edmonton, Churchill and Goose Bay) were co-ordinated from January to March with ozonesondes released at European stations. The aim was to optimize the timing of ozone soundings so as to be able to differentiate ozone depletion resulting from chemical changes and that from atmospheric dynamics. To accomplish this, the same air mass must be sounded for ozone at least twice during its passage over ozonesonde stations from continent to continent. Preliminary results indicate that chemical ozone depletion has indeed occurred this winter and spring at the higher latitudes. The final results of this collaborative research will be presented at this year's Quadrennial Ozone Symposium. Through this collaboration the Branch has gained access also to the European atmospheric measurements and analyses which are valuable for research into causes of ozone depletion.

Ozone depletion has indeed occurred this winter and spring at the higher latitudes

2.4.3 Ground-based FTIR Measurements
- H. Fast

To improve the capability of monitoring simultaneously a large number of atmospheric gases implicated in stratospheric ozone depletion and the greenhouse effect, monitoring has been undertaken at the Centre for Atmospheric Research Experiments (Egbert, Ontario) using the low-resolution Fourier Transform Infra-Red (FTIR) spectrometer. The new high-resolution Bomem FTIR system is being tested, adjusted and fitted with new input optics. This new system will be much more efficient and more accurate for monitoring a large number of gases.

New system will be much more efficient and more accurate for monitoring gases

2.4.4 World Ozone and UV Radiation Data Centre
- E.W. Hare, D.I. Wardle and J.B. Kerr

The World Ozone and Ultraviolet Radiation Data Centre (WOUDC) has two component parts: the World Ozone Data Centre (WODC) and the World Ultraviolet Radiation Data Centre (WUDC).

The WODC processes, archives and publishes world ozone data reported by over 300 stations. These data are published bi-monthly in a publication entitled "Ozone Data for the World" along with an annual catalogue which details all the data received each year. Data are current to the end of 1995. Data output from several data collection and measurement techniques comprise the database input which includes: total column ozone, surface ozone, vertical profile data derived from lidar, ozonesonde and Umkehr techniques. Total ozone measurements are made using several different instruments, most notably the Dobson and Brewer spectrophotometers.

Ozone data available up to the end of 1995

The Brewer also collects high resolution ultraviolet (UV) spectral data and now Japan and Canada regularly submit yearly UV data to be posted on the ftp server for world-wide use. The WUDC now has about 65 station-years of spectral UV data measured by the Brewer spectrophotometer. These data are from four stations in Japan and five in Canada.

Over 65 station-years of ultraviolet data available

The WOUDC has provided data by means of the Internet (ftp site) since January 1995. International sites made up well over half of the clients exchanging data by means of this WOUDC site. A preliminary WWW homepage has been available on a trial basis and a refined version is currently under construction. Staff members are working to establish a WOUDC Internet (ftp and Web) site which will house all the WOUDC data inventory (stratospheric ozone and spectral UV) along with NAtChem (precipitation) and CAPMoN (precipitation and air) data.

2.5 CLIMATE CHANGE

2.5.1 Carbon Cycle Research
- K. Higuchi, D. Chan, C. Blanchette, C.W. Yuen and Y.-H. Chan

The main research mandate of the Interpretation and Modelling Group (IMoG) is to model the climate/carbon cycle and to interpret the atmospheric CO_2 and CH_4 measurements. During the year, IMoG modified and improved the 2-dimensional climate/carbon cycle model. For the 2-dimensional global ocean model, the group incorporated the Fasham biological carbon cycle. Two projects were initiated: the development of a 2-dimensional interactively coupled climate/photochemical model, which stretches from the ground surface to 60 km in the stratosphere, and the development of a 3-dimensional interactively coupled global climate/carbon cycle model. Atmospheric and ice core CO_2 and CH_4 measurements obtained by the group at Tohoku University, Japan, were interpreted in terms of their latitudinal distribution of sources and sinks using a 2-dimensional atmospheric transport model developed by IMoG.

A modified and improved 2-dimensional climate/carbon cycle model

The group were helped through collaboration with Charles Lin (McGill University), H.-R. Cho (University of Toronto), Gerry Holdsworth (Unviversity of Calgary), Center for Atmospheric and Oceanic Studies, Tohoku University, and C.S. Wong (IOS).

2.5.2 Light Extinction in the Borden Forest

- R.M. Staebler, J.D. Fuentes and J. Deary

During the 1995 Borden field study, components of the solar and terrestrial radiation budget were measured both above and below the canopy. The above-canopy instruments were mounted in fixed positions on the tower, whereas the below-canopy measurements were made from a trolley moving on a 30 m track in order to obtain representative data over a statistically meaningful number of tree spacings. In addition, extensive measurements of the leaf area index were made with plant canopy analyzers, supported by leaf litter collection in the fall. The set of measurements are currently being analyzed, giving a more comprehensive picture of the canopy architecture and its interaction with light.

More comprehensive picture of the canopy architecture and its interaction with light

APPENDIX

Publications and Staff Information

AIR QUALITY RESEARCH BRANCH

PUBLICATIONS 1995/96

JOURNAL PUBLICATIONS 1995/96

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Barrie, L.A.	Atmospheric chemistry; Arctic haze; atmospheric removal processes - wet and dry
Bottenheim, J.W.	Atmospheric chemistry; measurements; modelling; nitrogen chemistry
Daggupaty, S.M.	Air quality modelling; transport and dispersion in boundary layer; mesoscale meteorology
Higuchi, K.	Global biochemical cycles and climate research
Hoff, R.M.	Lidar and DIAL; remote sensing; toxic chemicals; Arctic haze
Hopper, F.	Naturally emitted compounds & their impact on climate
Kerman, B.R.	Boundary layer turbulence; acoustic sounding; underwater sound; air-sea interactions; gas/particle exchanges
Kerr, J.B.	Ozone depletion; ozone trends; UV radiation
Lane, D.A.	Photochemistry of PAH; properties of PAC; mass spectrometry; instrument/methods development
Lo, A.K.	Meteorological parameters and flux profile relations in transport and deposition of air pollutants
Matthias, C.S.	Short range dispersion modelling
McArthur, L.J.B.	Solar radiation; UV radiation; measurement techniques
McElroy, C.T.	Remote sensing of atmospheric constituents and pollutants; UV radiation
Mickle, R.E.	Measurements of planetary layer using tethersondes; drift and deposition of pesticides from aerial application
Neumann, H.H.	Dry deposition measurement; micrometeorology; air pollution
Padro, J.	Boundary layer; dry deposition; climate
Schroeder, W.H.	Atmospheric chemistry; toxic chemicals
Trivett, N.B.A.	Microclimatology; energy balance; RAGS monitoring
Walmsley, J.L.	Computer modelling of wind flow in complex terrain
Wardle, D.I.	Ozone science; UV radiation
Wiebe, H.A.	Atmospheric chemistry; environmental chemical measurements; acid precipitation; network operations

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