PROGRAMME
FOR
ATMOSPHERIC WATER SUPPLY
(PAWS)

PHASE 1
1983 - 1986 FINAL REPORT

VOLUME 1
Executive Summary

Report to the
Water Research Commission
Pretoria, South Africa

by

Simpson Weather Associates, Inc
Charlottesville Va., USA

Cansas International Corp. (Pty) Ltd
Nelspruit, South Africa

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VOLUME I

Executive Summary

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Abstract

The central objective of the research carried out under the Programme for Atmospheric Water Supply (PAWS) is to evaluate the potential for beneficial modification of summertime convective rainfall over and near the escarpment of the Eastern Transvaal.

The work completed over the past four years has established a seeding procedure, identified and defined a seeding target, documented a seeding response of that target and established the foundation for a credible and consistent seeding hypothesis.

The seeding response has been documented by observing changes in the physical properties inside new growing cells of medium-sized multicellular cloud complexes and in the overall response, as measured by radar, of the cloud complex itself. The seeding response of the cloud complex as measured by radar can be followed up to 40 min after seeding showing a serial progression over time of successive physical responses. Initial changes detected in the vertical profiles of the storms are followed by an increase in the rates of upward and downward mass transports, terminating in an increase in radar measured rain flux at cloud base. By 30-40 minutes after initial seeding, the treated storms as measured by radar, occupy greater volumes, cover larger areas and have generated more radar measured rain at cloud base than their untreated counterparts.

Evidence that suggests that both dynamic and microphysical effects may be taking place is found in measured high supercooled water contents and low precipitation efficiencies due to high condensation rates and cloud water contents and low concentrations of large particles.

Continuation for one or more seasons of the exploratory randomized seeding experiments is desirable to increase sample sizes and confirm present findings. The design and execution of a randomized area rainfall enhancement experiment could then proceed.

Acknowledgements

We wish to express our gratitude and appreciation to the Chairman of the Water Research Commission and through him to the Commission itself for support of this research. We are grateful for the enlightened guidance and encouragement received from Dr. Peter Roberts over the past four years.

There are many individuals and other organizations both in the community of Nelspruit and the Lowveld and elsewhere who deserve recognition for supporting this research. We are most grateful for their help.

Preface

The Program for Atmospheric Water Supply (PAWS) has been and is expected to continue to be a sustained effort to determine first, the potential for rain enhancement and ultimately, the means by which water supplies can be augmented by the treatment of summertime convective clouds.

The four year PAWS project has been a detailed scientific and technical effort aimed at clear goals. A full accounting of the Project is now due and that is a formidable task with many components. We have broken this task down into the preparation of four volumes, each with a distinct potential audience.

Volume I is a succinct statement of the conclusions with a minimum of qualifying comments; it is the sum of our success or lack of it and is written for a wide and non-technical audience.

Volumes II and III are a full description of our findings, first on the nature of the clouds and their surroundings in the Nelspruit area and then on the rain augmentation experiments that have been carried out. The audience for these two volumes is a scientific one.

Volume IV is the technical and scientific foundation of the entire Final Report in which we set down in detail what we did and how we did it. The audience for Volume IV consists of scientists and engineers practicing in the fields of meteorology, cloud physics and weather modification.

The staff of each of the responsible organizations who performed this work is listed in Appendix A of this volume.

Appendix B lists the publications which have already been generated under this programme and provides a list of those manuscripts submitted for publication. These, and many other papers which will follow, will represent the main test of and the intellectual reward for the work done under PAWS.

Appendix C lists those individuals who served on the Steering Committee and guided this work over the past 4 years.

Appendix D provides a table of contents for the companion volumes.

1.0 RESEARCH OBJECTIVES

The ultimate aim of weather modification research is to evaluate the potential and to determine the methods required for beneficial modification of the weather. The objectives of the Programme for Atmospheric Water Supply (PAWS) at Nelspruit were refined at a workshop held in Charlottesville, VA during June 1983. These objectives are in accordance with the recommendations made to the Commission by the overseas consultants in June 1982.

The PAWS central objective is to evaluate the potential for beneficial modification of summertime convective rainfall in the region over and near the escarpment of the Eastern Transvaal. The 4 year programme is the initial phase of a longer research programme and was designed to:

1.1 Define a seeding target, and

1.2 Establish a seeding response.

To achieve these objectives, answers were sought to the following questions:

a. Do any of the clouds which occur in the experimental area show potential for rain augmentation?

b. Which class or classes of cloud systems in the experimental area (as described by radar and atmospheric measurements) constitute a feasible target for cloud seeding?

c. How often do such classes of clouds occur and what is their contribution to natural rainfall in the area?

d. Where and when do they occur?

e. How do they respond to experimental seeding?

f. Is that response, if any, consistent with a credible physical hypothesis or hypotheses?

Satisfactory answers to these questions lead to a "seeding hypothesis" which would then form the basis of an experiment designed to test the validity of man-induced changes in rainfall as measured at the ground over a specified area as opposed to the changes in rain production of a single cloud system.

Dry ice was selected as the seeding agent in the experiments conducted in the PAWS because:

a. airborne tests documented dramatic changes in cloud microphysics some 3 to 6 minutes after dry ice treatment;

b. dry ice is experimentally "clean"; once the pellets have evaporated the nucleating effect of the dry ice is gone; there is no "holdover" effect, as with silver iodide, and no potential for contaminating other experimental units.

The seeding that was carried out during the current phase of the programme was exploratory only, serving as a research tool to aid in understanding the local precipitation processes. No attempt has been made to increase area rainfall.

2.0 BACKGROUND

2.1 The water needs of South Africa and the rainfall augmentation option

Since South Africa's water supply is obtained from the atmosphere, research into those aspects of the atmosphere that impact upon water resources may be regarded as a necessity. The search for alternate sources of water has been spurred by estimates that local demand will exceed total available supply by the year 2020. Researchers must investigate the feasibility of tapping unconventional sources of water to augment the supply. Some of these are rainfall stimulation, desalination, towing icebergs from the Antarctic, importing water from neighbouring states, purification and re-use of effluents and various means of manipulating the hydrological cycle (evaporation and runoff harvesting).

Rainfall augmentation is an attractive alternate source of good quality water. Estimates of costs in other areas of the world indicate that cloud seeding might produce water for as little as 2 American cents a cubic metre, a fraction of the current cost of water in South Africa.

It has been estimated that atmospheric moisture moving over South Africa amounts to some 6 000 000 million cubic metres of water annually. About 10 percent of this total, or 600 000 million cubic metres falls as rain. Ninety percent of this rain (540 000 million cubic metres) returns to the atmosphere via evapotranspiration leaving 60 000 million cubic metres. Of this total, about 10 percent is lost to deep ground water storage and seepage into the sea so that the amount that runs off in South Africa's river system is about 54 000 million cubic metres per annum. It is not possible to dam all this river flow. Estimates are that some 33 000 million cubic metres of this water are exploitable or one half of one percent of the total moisture moving over the country each year. If rainfall augmentation was capable of increasing the annual rainfall over the whole country by 20 percent, this would amount to extracting only 1.2 percent of the moisture from this vast reservoir that traverses the country each year. It would be grossly irresponsible not to explore the possibilities of tapping this enormous reservoir of fresh water.

2.2 Immediate history

An operational hail suppression programme, funded by the local tobacco cooperative, the Laeveldse Kooperasie Beperk (LKB) was initiated at Nelspruit in November 1971. The effects of the hail suppression seeding on the rainfall became a strong local concern.

The assistance of the Water Research Commission (WRC) was solicited to study this problem. Historical data together with greatly improved in-cloud measurements were used by Simpson Weather Associates (SWA) and Cansas International Corporation (CIC) in a 3 year study supported by the WRC of the effects of hail suppression on rainfall. Lack of statistical control precluded definitive results beyond suggesting that no deleterious effects of hail suppression seeding could be found. Increases in rainfall were found which could not be ascribed with any certainty to seeding.

On March 30, 1981, coincident with the end of the WRC supported research programme, the LKB terminated the operational hail suppression programme.

Concern that research capability as well as promising research findings would be lost led to a one year extension (to December 1982) of the work being done by CIC and SWA and the appointment of a panel of international experts in the field of weather modification and cloud physics to evaluate the work being done at Nelspruit.

The panel concluded that an excellent base had been established at Nelspruit from which further research into the feasibility of rain augmentation in the area could be launched. At a meeting held at the Commission on 5 July 1982 at which the report by the consultants was critically considered, it was proposed that the Chairman should initiate negotiations with all relevant parties with the aim of continuing the rainfall augmentation research at Nelspruit for a period of 3 to 4 years. During these negotiations, legal advisors to the WRC advised that the lease or purchase of aviation equipment for water research purposes would place the Commission in a position of unacceptably high risk. A non-profit company was thus established, the Company for Research on Atmospheric Water Supply (CRAWS), to conclude the necessary purchases and agreements required to continue the research. SWA was appointed as principal investigators and CIC (Pty) Ltd. was contracted to operate the equipment at Nelspruit under guidance from SWA. The necessary equipment was purchased from the LKB. The 4 year agreements, which commenced on 1 January 1983, expired on 31 December 1986.

3.0 RESULTS

The PAWS was designed to identify a seeding target and determine whether a seeding response could be detected and verified after the treatment of that target. Development of a "seeding hypothesis" expressed in terms of physical processes follows upon the detection and verification of a seeding response. The research is designed to assess the potential for augmenting rainfall from summertime convective storms over the eastern Transvaal and not to attempt to systematically increase rainfall at the ground.

A seeding target has been specified and defined as a medium-sized, isolated multicellular convective storm identifiable in radar terms. It is large enough to be relatively long lasting with an associated source of supercooled liquid water. The medium-sized convective complex occurs on most convective days and produces a significant part of the natural rainfall of the eastern Transvaal.

The dry ice seeding is targetted into turrets rising through the -10°C level on the flanks of convective complexes. The new growth seldom shows a radar echo at time of treatment, however, the radar is used to vector the aircraft into the region of anticipated new cloud growth (usually the west to northwestern flank of the storm). Each turret is seeded once and all turrets are treated for a total seeding time of 120 seconds (each run averages about 10 seconds, therefore on average, about 12 turrets will be treated at a seeding rate of 200 g/s.

Randomized selection of targets result in seed and no-seed cases. Over the two seasons (1984/85 and 1985/86) 32 seed and 37 no-seed cases could be compared. The response of the cloud complex could then be obtained by examining a large number of radar response variables over the track of that storm from seeding time up to 40 minutes after seeding. This procedure produces the most fundamental seeding response yet to be obtained in the PAWS. The result is particularly important because statistical analysis shows a serial progression over time after seeding of physical events which are predicted by the seeding hypothesis. Thus, in the first 10 min after seeding, there is an upward change in the vertical profiles of the seeded storms. This is detected by an upward displacement of the centre of mass of the storm. This is followed by an increase in the upward rates of mass transport, then a rapid transport of mass downwards which is detected at cloud base as an increase in radar measured rain flux. By 30 - 40 minutes after initial seeding, the seeded storms, as measured by radar, occupy greater volumes, cover larger areas and have produced more rain than their untreated counterparts.

These findings are supported by a systematic shift to higher significances in the probability value distributions of the 147 track properties which occurs as time after initial seeding is increased from 10 to 40 minutes.

An analysis of the probability distributions for each season also reveals a consistency in the responses of key variables, demonstrating that the results from a single season are not dominating the statistics of the combined analysis. If a third season reflects these initial results, then acceptable levels of statistical significance for the exploratory phase of the experiment should be achieved.

New instrumentation developed in PAWS shows that, in the absence of precipitation particles in the clouds, average supercooled liquid water contents of 4.0 g m^{-3} occur compared to 2.5 g m^{-3} as measured by previously existing instrumentation. More than half of the 4.0 g m^{-3} liquid water mass is in the form of particles larger than cloud drops which can be rapidly frozen by dry ice seeding. Freezing of these drops could yield a 0.75°C rise in temperature at the -10°C level in the clouds, thus making a significant contribution to the buoyancy of the cloud.

Microphysical measurements carried out in a large number of clouds during the PAWS suggest that the natural clouds are of low precipitation efficiency, i.e., they do not naturally possess precipitation embryos which will rapidly sweep up the available cloud water and convert it into precipitation. Two indices developed during the PAWS, the Conversion Efficiency Index and the Reservoir Effect Index to measure the efficiency of natural clouds in producing precipitation and the effectiveness of seeding to augment the deficiency in the precipitation embryos, provide a basis to assess these critical cloud microphysical processes. (Caution must be taken when interpreting these results. The Conversion and Reservoir indices are measured locally, and may bear no relationship to overall storm precipitation effeciency).

The high liquid water contents and the low precipitation efficiencies of the Nelspruit clouds suggest that both a dynamic and a microphysical response to seeding can be expected. The dynamic response following the release of latent heat of fusion when the supercooled liquid water is frozen by the dry ice particles is to increase the cloud buoyancy, invigorating the cloud (increase in height, diameter, and vertical velocity). The invigorated cloud processes more atmospheric water vapour and the cloud produces more rain. The microphysical response due to the supply of precipitation embryos introduced by the dry ice causes precipitation to begin earlier than in the natural case as well as to proceed more efficiently. The use of dry ice as a seeding agent would appear to initiate both dynamic and the microphysical responses described above.

An extensive radar climatology of the thunderstorms of the Lowveld Escarpment has been accumulated in the PAWS. The structure is archived in the form of

a. digital radar data;
b. cloud physical data from aircraft, in database format;
c. automated recording raingauge data;
d. automated recording surface mesonet station data;
e. radiosonde data (including aircraft data) in data format.

Analytical procedures together with extensive software have been developed to interpret these data. Procedures have been developed to predict the occurrence of clouds suitable for rain enhancement. Warm cloud base conditions and low buoyancy favour the occurrence of large drops and a positive response to seeding.

Prediction of storm behaviour and internal characteristics has also been improved by using the surface measurements from 9 meteorological towers spaced about 50 km apart across the escarpment. These towers have provided observations from which air flow into and out of the escarpment and surrounding areas can be calculated. Storm outflows have been simulated by computer using the radar and sounding data. Regions of cloud outflow interaction have been determined with the view to identifying the most favourable seeding locations.

Analysis of the frequency of occurrence of "seedable" storms, based on radar and the above forecast procedures, suggests that operational area-wide seeding could produce as much as 15% more rainfall over the experimental area. No negative effects due to the limited exploratory randomized seeding experiment could be detected.

4.0 TOOLS AND EQUIPMENT

The PAWS began operations in 1982 with the following major systems on hand.

* A Learjet 24 equipped with cloud physics instrumentation and a spare jet engine;

* A 5 cm wavelength weather radar with an aircraft tracking capability and an associated computer capable of displaying and storing digitized radar data;

* a radiosonde sounding system capable of tracking (winds) and receiving radio signals (pressure, temperature and humidity from balloon-launched radiosondes;

* Electronic test and radar calibration equipment.

Considerable additional equipment was added or refinements made to existing systems. These include:

* A cloud base aircraft (Aero Commander 500S) was purchased and equipped with cloud physics instrumentation similar to that on the Lear. The main role of this aircraft is to measure storm rainfall at cloud base and to compare these measurements to those of the project radar.

* A nine-station meteorological 10 m tower network was developed and deployed on a 50 km grid across the escarpment. This network measured 5 minute averages of wind speed and direction, pressure, temperature humidity and rainfall.

* 16 automatic tipping bucket raingauges were installed in an array around the Vyeboom Dam in the Badplaas valley. Rainfall measurements every 5 minutes from this automatic network have provided valuable information on storm rainfall rates and on the diurnal distribution of convective rainfall. A comparison of rainfall rates and radar returns has led to the derivation of a relationship to estimate rainfall from the radar return.

* A new mini computer was acquired during the second year of the project. The power of this new system eliminated the analysis bottlenecks caused by the huge amounts of data generated by the aircraft, radar and surface measurement systems. It also permitted the development of "data banks" for the aircraft and radar. All data from these sources can be quickly retrieved, manipulated or copied for outside users by using the data banks and computer programmes developed for these purposes.

* A satellite receiving system was installed late in the third year of the contract period. Visible and infrared photographic pictures received from the European satellite, Meteosat, every 3 hours during daylight hours have greatly enhanced the ability to forecast the arrival of cold fronts. Much of the experimental activity is focussed on the convective storms that break out in advance of these weather systems.

* Conversion to a volume scan mode of operation. Eighteen horizontal (360^{o}) scans from 3 through to 50 degrees in the vertical are completed each 5 to 8 minutes, digitally recording radar returns on all storms within a radius of 10 to 120 km from the radar. These data, along with aircraft tracks from the cloud base and Learjet aircraft are stored on magnetic tape. Computer control of the radar ensures flexibility; any changes to the sytem are effected by simply altering the programme.

* Addition of a colour visual display unit. The contoured 3 degree scan is displayed on this unit, updated at the beginning of each volume scan sequence. This presents a current display of the locations and intensities of the storms in the area, and is extremely useful during flight operations.

Perhaps one of the most valuable accomplishments is the development of computer programmes to store, analyze and display the vast amounts of data that have been acquired during the 4 project years. Without these programmes, it would have been impossible to rationally process the data acquired to date.

Less tangible but no less valuable are the knowledge, measurement and research skills accumulated by the project staff over the past 4 years.

5.0 CONCLUDING REMARKS

The PAWS has achieved much over the past 4 years. The extent of the achievement and the degree to which the original objectives have been met await further analysis and wider assessment. Support should be provided for this analysis because both wider acceptance as well as more analysis by others will depend upon the publication of the PAWS results in recognized international scientific journals.

Sample size and the possibility of bias remain as problems. It is desirable that at least one more season of measurements be carried out to augment those acquired over the past 2 years. Recognition must, however, be given to the fact that considerable resources should now be devoted to interpretation and assessment. Results, if they continue to support a positive seeding response, should be used to

* carefully assess the impact of this positive response on runoff and available water;

* design an area-wide randomized seeding experiment to assess changes in rainfall at the ground over a target area of sufficient size to be of hydrological importance;

* delineate areas in which measurement capability is weak or lacking with the view to strengthening these areas prior to the execution of any area-wide experiment;

* examine the transferability of the Nelspruit results to other areas in South Africa and to compare these results with results obtained in other locations both within and outside of the boundaries of the Republic.

APPENDIX A

Paws Personnel

Simpson Weather Associates Inc.

Michael Garstang , Programme Director
Griffith M Morgan, Principal Field Scientist

John Boisseau, Programmer
Henry J Cooper, Atmospheric Dynamicist
George D Emmitt, Atmospheric Scientist
Karen Emmitt, Typist/Data Analyst
Sherry H Heitchew, Programmer
Samuel Houston, Programmer
Wendy London, Programmer
Charles Martin, Electrical Engineer
Deborah Martin, Technician
Mary Morris, Administrative Assistant
Doug Young, Programmer

Cansas International Corporation (Pty) Limited

Graeme K Mather , Operations Director

M J Dixon, Radar Analyst/Programmer
Maureen Dreyer, Secretary
Charles Mather, Rainfall Studies
Peter McNaught, Technician
Brian J Morrison, Cloud Physicist/Programmer
Matthew Horton, Pilot
Rob Parsons, Programmer/Pilot
Ian C Ross, Technician
Fritz van der Westhuizen, Chief Pilot
V Wightman, Programmer/Pilot
Ken Young, Electrical Engineer

Non-SWA/CIC Personnel

N Human - Department of Agriculture
C Welgemoed - Department of Agriculture

APPENDIX B

PAWS Publications

Conference Proceedings and Presentations

Diab, R.D. and M. Garstang, 1986: Classification of synoptic weather regimes in South Africa by discriminant analysis. Proceedings of the 2nd Internat. Conf. on Southern Hemisphere Meteorology, Wellington, New Zealand, 1-5 December.

Dixon, M.J., 1983: The development and application of volume scan and cell tracking capabilities for the analysis of convective cloud systems. Symposium on Atmospheric Science in South Africa, Pretoria, 18-20 October.

------, M.J. and G.K. Mather, 1986: Radar evaluation of a randomized rain augmentation experiment - some preliminary results. 10th Conf. on Weather Modification Proceedings, Arlington, VA, 27-30 May, 139-141.

Emmitt, G.D., 1984: Behavior of cylindrical dry ice pellets - field, laboratory and model experiments. Proceedings of 9th Conf. on Planned and Inadvertent Weather Modification, Salt Lake City, 21-23 May, 20-22.

------, 1985: Discrimination of local and synoptic scale forcing of cumulus convection along the eastern Transvaal escarpment using Meteosat imagery. 2nd Annual Conf. of the S.A. Society for Atmospheric Sciences, Pretoria, 11-12 November.

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------, 1986: Topographical influences on the temporal and spatial distributions of seeding opportunities - implications for PAWS. 3rd Annual Conf. of the S.A. Society for Atmospheric Sciences, 7-8 October, Pretoria.

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------, and G.D. Emmitt, 1983: Anatomy of a drought. Symposium on Atmospheric Science in South Africa, Pretoria, 18-20 October.

------, and B.E. Kelbe, 1986: Generation of convective storms over the escarpment of the eastern Transvaal. 3rd Annual Conf. of the S.A. Society for Atmospheric Sciences, 7-8 October, Pretoria.

Kelbe, B.E. and M. Garstang, 1983: The initiation of deep convection over northeastern South Africa and Swaziland. 1st Internat. Conf. on Southern Hemisphere Meteorology, 31 July - 6 August, Sao Jose Dos Campos, Brazil.

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London, W. and G.D. Emmitt, 1986: Topographical influences on radar echo properties - implications to weather modification projects in mountainous terrain. 10th Conf. on Weather Modification Proceedings, 27-30 May, Arlington, VA, 169-174.

Mather, G.K., 1983: A preliminary microphysical description of eastern Lowveld clouds. Symposium on Atmospheric Science in South Africa, Pretoria, 18-20 October.

------, and K.R. Gabriel, 1984: Some analysis of summer rainfall at Nelspruit, South Africa. Proceedings of 9th Conf. on Planned and Inadvertent Weather Modification, Salt Lake City, Utah, 21-23 May, 120.

------, and M.J. Dixon, 1985: Preliminary results from the Nelspruit 1984/85 seeding experiment. 2nd Annual Conf. of the S.A. Society for Atmospheric Sciences, 11-12 November, Pretoria.

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------, 1986: Towards a confirmatory seeding experiment at Nelspruit. 3rd Annual Conf. of the S.A. Society for Atmospheric Sciences, 7-8 October, Pretoria.

Morgan, G. and G.K. Mather, 1984: Problems in the measurements of liquid water content in Transvaal clouds. Proceedings of 9th Conf. on Planned and Inadvertent Weather Modification, Salt Lake City, Utah, 21-23 May, 24.

------, 1985: Jet engine bleed-air measurements of water quantities in convective clouds. 2nd Annual Conf. of the S.A. Society on Atmospheric Science, 11-12 November, Pretoria.

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Morrison, B.J., W.G. Finnegan, R.D. Horn and L.O. Grant, 1984: A laboratory characterization of dry ice as a glaciogenic seeding agent. Proceedings of 9th Conf. on Planned and Inadvertent Weather Modification, Salt Lake City, Utah, 21-23 May, 8-9.

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Garstang, M., B.E. Kelbe, G.D. Emmitt and W. London, 1986: Generation of convective storms over the escarpment of northeastern South Africa. Published in the December issue of Mon. Wea. Rev.

Manuscripts Submitted or Under Preparation

Cooper, H.J. and M. Garstang: A conventional radar-based nowcasting algorithm for surface winds beneath precipitating convective systems. To be submitted to J. Clim. and Appl. Meteor.

Emmitt, G.D., D. v.d.S. Roos and B. Morrison: Behaviour of cylindrical dry ice pellets. Under preparation.

Mather, G.K., and B.J. Morrison and G.M. Morgan, 1986: A preliminary assessment of the importance of coalescence in convective clouds of the eastern Transvaal. Submitted to J. Clim. Appl. Meteor.

Morgan, G.M., B.J. Morrison and G.K. Mather, 1986a: Total condensed water contents in warm-based thunderstorm turrets: Their estimation with a jet engine bleed-air measurement technique. Submitted to J. Clim. Appl. Meteor.

------, ------ and ------, 1986b: Sensing of cloud condensed water mixing ratio in jet engine compressor bleed-air by the potential temperature method. Submitted to J. Clim. Appl. Meteor.

------, ------ and ------, 1986c: Evidence for the accumulation of very high concentrations of supercooled liquid water in thunderstorms. Submitted to J. Clim. Appl. Meteor.

APPENDIX C

PAWS Steering Committee

The following individuals served on the PAWS Steering Committee:

Chairman:	Dr. P.J.T. Roberts	Water Research Commission
Secretary	D.J.G. Thiart F.P. Marais	
	Mr. E. Braune	Dept. of Water Affairs
	Mr. D.W.H. Cousens	Company for Research on Atmospheric Water Supply
	Dr. A.L. du Pisani Mr. Nico Human	Dept. of Agriculture and Water Supply
	Mr. P. van Wyk	National Parks Board
	Dr. A.E. Carte Dr. D. Roos	Council for Scientific & Industrial Research
	Dr. P.S. du Toit Mr. J. Groenewald	Dept. of Environment Affairs/Weather Bureau
	Mr. P.F.D le Roux Mr. C. van Veijeren	Laeveld Kooperasie Beperk
	Mr. I.T. Spear	Louws Creek Farmers Assoc.
	Mr. G.C. Nel	Lydenburg Farmers Assoc.
Reporting: Associates		
	Dr. M. Garstang Mr. G. Morgan Dr. G.D. Emmitt	Simpson Weather Assoc.
	Mr. G.K. Mather	Cansas International Corp.

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VOLUME IV

Instruments, Techniques and Studies

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