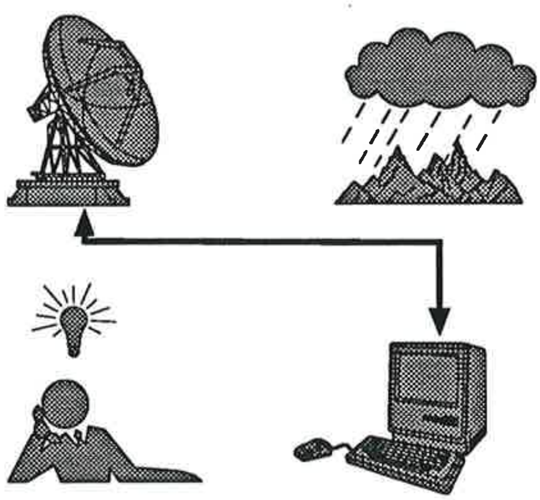
Taihoro Nukurangi

SUMMARY OF THE NATIONAL SYMPOSIUM ON THE HYDROLOGICAL APPLICATIONS OF WEATHER RADAR

22-25 February, 1994
Wellington, New Zealand



NIWA Science and Technology Series No. 2

ISSN 1173-0382

NIWA Science and Technology Series No.2

Summary of The National Symposium on the Hydrological Applications of Weather Radar

22-25 February 1994
Wellington, New Zealand

A meeting to advance the use of Weather Radar in New Zealand

Edited by Alaric Tomlinson & Warren Gray

This symposium was jointly sponsored by Meteorological Service of New Zealand Ltd and National Institute of Water and Atmospheric Research Ltd

NIWA
Wellington

June
1994

Cataloguing-in-publication

Tomlinson, A.I.

Summary of the national symposium on the hydrological application of weather radar / A.I. Tomlinson and W.R. Gray, Wellington, NZ: National Institute of Water and Atmospheric Research Ltd, 1994. (NIWA science and technology series; 2)

ISSN 1173-0382
ISBN 0-478-08330-0

I Gray, W.R. II National Institute of Water and Atmospheric Research Ltd.
III Title. IV Series.

The *NIWA Science and Technology Series* is published by NIWA (the National Institute of Water and Atmospheric Research Ltd.), New Zealand. It supersedes the NIWA Ecosystems Publications (ISSN 1172-3726; published by NIWA Ecosystems, Hamilton), New Zealand Freshwater Research Reports (ISSN 1171-9842; published by NIWA Freshwater, Christchurch) and Miscellaneous Publications, New Zealand Oceanographic Institute (ISSN 0510-0054).

Available from:

Publications
NIWA-Climate
PO Box 3047
Wellington
New Zealand

Ph. 04 472 9966
Fax 04 496 9414

or

Publications
NIWA-Ecosystems
PO Box 11-115
Hamilton
New Zealand

Ph. 07 856 7026
Fax 07 856 0151

or

Publications
NIWA-Marine
Private Bag 14-901
Kilbirnie, Wellington
New Zealand

Ph. 04 386 1189
Fax 04 386 2152

THE NATIONAL SYMPOSIUM ON HYDROLOGICAL APPLICATIONS OF WEATHER RADAR

Wellington, 22-25 February 1994

INTRODUCTION

The programme for this workshop is given in Appendix 1. Prior to the Symposium a preprint volume of Abstracts was produced and circulated to those attending the Symposium.These proceedings do not duplicate those abstracts but instead do the following:

1. Summarise the *requirements of users* and potential users of weather radar as these were expressed at the Symposium .

2. Document the *Workshops* conducted by Professors Collier, Cluckie and Austin during the Symposium.

3. Present the findings from the *working groups* which considered various uses of weather radar in New Zealand.

Appendix 2 contains a complete list of names and addresses of people who attended the Symposium.

USER REQUIREMENTS

1. Lennie Palmer, Electricity Corporation NZ Ltd.

Reported a need for improved weather forecasts of various types including:

- Forecasts of temperature changes. 1 ^{o}C equates to about 2% change in power demand at the consumer end.
- Forecast of snow amount and melt.
- Precipitation forecast for monitoring cloud seeding work.
- Forecasts of wind as an energy source. More climate wind information for siting generators.
- Short-term accurate forecast of precipitation for timing of inflows to hydro-storage lakes.

In addition the need to understand processes was emphasised.

2. Darryl Lew, Wellington Regional Council.

Reported a need for:

- Increased flood warning time and more accurate rainfall and flood warnings.
- Good reconciliation of radar echo with precipitation at ground level.
- Improved software for flood forecasting.

3. Graeme Horrell, Canterbury Regional Council.

Reported a need for:

- Improved flood forecasting especially for rivers draining the foothills (and not the main divide).
- More studies in how to input data to flood forecasting models.

4. Tim Rix-Trott, Auckland Regional Council.

Reported a need for:

- More detailed flood predictions.
- Augmented data collection by using radar data, to get better models.

5. Dave Parkin, Environment Waikato

Reported a need for:

- Radar data to fill substantial spatial gaps in current data collection.

WORKSHOP SESSIONS

First Workshop:
Professor Chris Collier, 'The Contribution of Raingauges, Radar and Satellites to Nowcasting'.

The following are the general conclusions from the Workshop. These were arrived at after presentations on the main questions by Chris Collier, and the discussions so generated.

1. *Adjusting radar data using raingauge data*

(a) Are the radar data accurate enough without adjustment using independent data ?

In general no, but there is a view that if the radar data are processed to take account of ground clutter, the vertical reflectivity profile etc. then there is no need to adjust further using raingauge data. Indeed, the use of raingauge data may in some circumstances introduce unwanted noise into radar estimates of precipitation.

(b) Can raingauge adjustment be detrimental - is raingauge adjustment dangerous ?

Yes, raingauge adjustment in the presence of bright band effects and in convective rainfall situations can be very detrimental. This is important as data adjustment needs to be reliable.

(c) When should raingauge adjustment be carried out ?

Perhaps it is reasonable to use raingauges to adjust radar data in situations and locations where orographic rainfall development is important. Raingauge adjustment should not be carried out in convective situations. However, raingauge data should be used extensively in off-line studies of orographic effects aimed at deriving real-time corrections to radar data.

(d) What techniques should be used for raingauge adjustment - stochastic or physics-based ?

Given that real-time adjustment of radar data with raingauge data should, at best, only be carried out in particular circumstances, both approaches might be used. Nevertheless, any technique employed must be underpinned by the physics of the processes it claims to represent.

(e) Will advanced radars (eg. Doppler, multi-parameter) remove the need for any adjustments ?

While multi-parameter radars seem to offer the prospect of measuring the distribution of hydrometeor sizes, such radars are no better at measuring orographic rainfall. In New Zealand, as elsewhere, they offer no advantage. Doppler radar offers improved ground clutter rejection and measurements of wind flow. However Doppler radar is unlikely to improve rainfall measurement accuracy except in providing additional information for the understanding of physical processes and for short-period forecasting system (these are considerable benefits). A view was expressed that rather than spend money on purchasing expensive Doppler radars, it might be more cost beneficial to spend money on cheaper reflectivity-only radars.

2. *Radar networking*

(a) Should data from individual radars be combined before raingauge adjustment or after ?

Such combination of data should take place after raingauge adjustment in order to make sense of the overlap regions between radars. It was noted that it might be better to put effort into correcting for the vertical reflectivity profile, in which case the question would not arise.

(b) Should radar network images be smoothed to hide areas of deficient coverage?

Most certainly not.

(c) What about use of higher elevation data / CAPPIs ?

CAPPIs are very useful in identifying/analysing multi-cellular events. However, in making measurements of rainfall with radar it is necessary to operate the radar at the lowest possible elevation. There seems to be a conflict between the importance put upon the use of CAPPIs by meteorologists and the requirements of hydrologists to measure surface rainfall. In practice it probably does not matter provided a very low elevation CAPPI is used.

(d) How can radars of different types be integrated operationally (conventional Z only, Doppler, multi-parameter) ?

The only practised approach is to network only like data eg. reflectivity with reflectivity, Doppler winds with Doppler winds. However, Doppler wind information can be used within a weather forecasting environment provided forecasters are highly trained in its use.

3. *Nowcasting* (an accurate representation of the weather now and forecasts for a few hours ahead)

(a) Single site forecasts versus wide area (multiple radars) forecasts

These approaches to forecasting really represent a difference in the availability of high resolution (<2 km, <5 minutes) radar data. If differences in data availability exist then the approaches are complementary, but networks should aim to process high resolution data.

(b) Is linear extrapolation useful ?

Linear extrapolation is useful for producing forecasts up to 3 hours ahead in frontal rain, although, depending upon the use to which the forecasts are put, it may be necessary to take account of the movement of embedded convective cells. The use of linear extrapolation in a convective situation is of very limited applicability. In general one should not try to forecast beyond the natural temporal cycle of systems (1/2 - 1 hour for deep convection and 3-4 hours for frontal rain).

(c) Can forecasts be made automatically or is a forecaster essential ?

Forecasts can be made automatically, but there is concern about what will happen during extreme events or when algorithms fail. A forecaster should be kept in the procedural loop. If arrangements are not made to do this then there is a real danger of losing the meso-meteorological skill base.

(d) What is the potential of artificial intelligence ?

Artificial intelligence (a better expression might be synthetic intelligence!) does hold great promise for short period forecasting provided systems are built around physical understanding of the appropriate atmospheric processes. It may be that expert systems etc. can be used to provide forecast guidance rather than absolute answers !

(e) Will mesoscale NWP models remove the need for data-based nowcasts ?

The question suggests that there is a real difference in approach to nowcasting, namely on the one hand starting with a numerical model and assimilating remotely sensed data, and on the other hand starting with remotely sensed data and regarding model output as yet further data. In fact this difference may only represent a difference in forecast time-scales, that is up to 1 hour ahead for data based; 3-6 hours ahead for data based plus model output; 24 hours ahead for model output. Perhaps therefore a difference in approach is being identified which is not really there. However, nowcasts should be seen as complementary mesoscale model forecasts and vice versa.

4. *Satellite data*

(a) Will satellite instrumentation remove the need for ground-based radar ?

Current experience suggests that the answer is no. This was discussed further in the workshop led by Professor Austin.

(b) Adjusting satellite data using radar and raingauge data

Geostationary satellite data are essential for nowcasting, although data from polar orbiter satellites (only two passes per day) are important for discriminating weather types as they provide high resolution data.

Second Workshop:
Professor Ian Cluckie, 'A Radar Hydrology Perspective : Crucial Current Issues in Radar Hydrology'.

Part 1. A Radar Hydrology Perspective.

In this part Professor Cluckie:

- Covered flood forecasting in general. In particular, real-time aspects of the problem and its dependence on precipitation measurement and exploitation of weather radar.
- Discussed the structure of appropriate mathematical models for application in real-time. It was emphasised that the models must accommodate feedback and allow for parameter updating.
- Discussed aspects of data resolution and provided guidance on the spatial and temporal resolution required from quantitative weather radar. Also discussed the issue of data quantisation which affects data accuracy and the preservation of the maximum information content in a given radar precipitation signal.
- C-band was noted as the common weather radar frequency (see also notes from Working Group 2, below).
- The STORM system (to Obtain Radar Measurements) was described. This allows manipulation of real-time weather radar data by remote access.
- The WRIP system (Weather Radar Information Processing) was described. This provides real-time flood forecasting using radar data in several regions in the UK.

The conclusions were:

1. Radar measurements of precipitation are suitable for the construction and operation of real-time flood forecasting models.
2. Spatial precipitation data are highly preferable to point raingauge data in the construction of operational flood models.
3. Models employing a feedback structure, such as Transfer Function Models, are most appropriate for operational use. Parameter feedback mechanisms in real-time are also desirable to maximise the applicability of these types of mathematical structure.
4. Radar data should typically be at a minimum of 5 km by 5 km spatial resolution (but ideally 1 km by 1 km), 15 minutes temporal resolution (many catchments typically requiring a 1 hour data interval) and a minimum quantisation of 3 bits (ie. 8 discrete levels of discrimination).
5. X-band is useful for research purposes but either C or S-band is required to provide reliable quantitative data for radii greater than about 20 km from the radar.

6. STORM and WRIP have proved their usefulness by being adopted in over one third of National River Authority areas in the UK.

Part 2. Crucial Current Issues in Radar Hydrology

In this part Professor Cluckie:

- Focused mainly on aspects of Urban Hydrology and covered in detail radar measurement errors, bright-band and new developments in vertically pointing radars, specifically Hydrological Radars.

- Introduced the problems that occur in large urban catchments where significant pollution is caused by combined sewer overflows on surface flooding during heavy rainfall.

- Discussed radar measurement errors but specifically focused on the problems of 'bright-band'. This is a significant problem in both New Zealand and the UK, and forms the major real-time correction to be made to radar measurements prior to successful numerical exploitation.

- Described the new X-band Vertically Pointing Radars (VPR) used for measurement of vertical reflectivity, and also introduced the new C-band Hydrological Radar currently under prototype development.

The conclusions were:

1. Calibration by networks of raingauges is very problematic. The problem of so called 'ground truth' is that raingauge networks give representative measurements during stratiform rainfall events but they generally do not during periods of convective activity. Experience with ground based correction procedures has therefore been very mixed and it is expected that this experience will be mirrored in New Zealand.

2. Quantitative radar measurement of precipitation over urban areas is useful in modelling the behaviour of complex urban drainage systems. In the UK this is from the perspective of introducing real-time control procedures into the management of large scale systems and minimising surface flooding and combined sewer overflows. In New Zealand the problem of urban flooding could be tackled by using both specially designed low-power hydrological C-band radars and the National Radar Network.

3. The resolution of radar data required for urban hydrology application is a minimum of 2 km by 2 km and 5 minutes. Data of smaller resolution (down to 250 m by 250 m and every 2 minutes) has significant benefits. Signal quantisation studies indicate that a 4-bit process preserves the majority of the information content of the precipitation signal.

4. Bright-band correction procedures are essential. The exploitation of mobile X-band VPR for studies of vertical reflectivity structures in the UK have proved of great benefit. It is recommended that a number of similar studies

be done in New Zealand, in both urban areas and orographically enhanced rainfall regions, using an X-band VPR. The development of a real-time bright-band correction algorithm is an essential prerequisite to the full exploitation of weather radar for quantitative precipitation measurement.

5. The provision of an experimental mobile C-band hydrological radar for use in various parts of New Zealand for essentially hydrological purposes is strongly suggested. This would be particularly useful for remote regions where rainfall input is poorly estimated by ground based procedures and remote sensing provides the only satisfactory alternative.

6. Radar data should, at the earliest possible time, be disseminated to hydrological users in real-time. It is essential that the hydrological community begins to assume ownership of some of the problems in developing suitable applications of weather radar in their area of science.

Third Workshop:
Professor Geoff Austin, 'The Accuracy of Rainfall Estimation'.

Conclusions from this workshop were as follows:

1. Raingauge networks can give large (30-50%) errors in the estimation of areal rainfall particularly in convective situations.

2. The use of sophisticated interpolation schemes has little impact on the accuracy of areal rainfall estimates from raingauges. Increasing the number of raingauges improves the accuracy but this becomes a diminishing return operation.

3. Satellite remote sensing techniques from orbiting satellites only give a twice a day coverage which yields very large (100% or more) errors in daily and even monthly precipitation.

4. Geostationary satellites have visible and infrared, and may have far infrared radiometers in the reasonably near future. None of these systems sees rainfall directly. The indirect techniques are not likely to become very accurate except perhaps for long term averages.

5. Weather radar may be the only way to measure corrective rainfall to reasonable accuracy.

6. The physical correction and quality control of weather radar data is painful but absolutely necessary for hydrological purposes.

7. Problems associated with local orographic effects and bright bands need to be addressed. Studies using vertically pointing radars and other equipment are under way in support of SALPEX and at other locations. These problems get more severe at longer range.

8. Small inexpensive C-band weather radar operating at short range can be very cost effective for some hydrological problems.

WORKING GROUPS

Working Group 1.

This group, lead by Professor Ian Cluckie, considered the problems and requirements associated with the prediction of major floods in New Zealand.

They raised the following points:

1. Data Access

   - MetService's 'Severe Weather Bulletins' for heavy rainfall alerts are very useful.

   - Regional Council staff need to be able to talk to forecasters at any time during a flood event.

   - Data from Regional Councils' telemetered systems, with pre-set alarm levels, need to flow to MetService.

   - MetService update forecast needed by Regional Councils.

2. Direct Access to Weather Radar

   - Regional Councils need real-time access during major storms (see also Working Group 2).

   - It was accepted that there would be costs attached to real-time access to cover 'value added' and other items.

   - An archive of radar data from major storms is needed for research and training by Regional Councils.

3. General Points

   - Radar data would add a great deal to flood prediction in large catchments, where precipitation results from large weather systems in which orographic enhancement is often pronounced.

   - In the urban situation short lead times in flash floods strongly detract from the value of weather radar.

   - Joint projects should be set up to establish flood prediction models using radars plus existing systems (between NIWA, MetService and Regional / Local Councils).

   - Models need to be as simple as possible and robust. Particular attention will be needed with respect to communications of data into real-time models.

   - Further work is needed to establish if 15 minute radar scanning is suitable.

- The 1 to 2 kilometre resolution of MetService radars is quite adequate for flood prediction.

- Improved warnings at lead times as short as 1 hour can be useful but 3 to 6 hours is better.

- Current telemetry run by Regional Councils is expensive. Radar data may be relatively cheaper and could assist in rationalising telemetered networks.

Working Group 2.

This group, lead by Professor Geoff Austin, discussed the question:

'Given the hydrological problems in NZ, should we be using raingauges, MetService radars, hydrological radars, or some combination of these ?'

They made the following recommendations:

1. The three MetService 5 cm radars are there and should be used more.

2. MetService should seriously consider reducing the 15 minute scanning cycle on their radars to 5 minutes. It was acknowledged that this would create a data storage problem.

3. A national archive of weather radar data is needed and should be operated on the same basis as the climate data archive.

4. To allow Regional and Local Councils access to and use of MetService radar data either MetService or someone else should develop a low cost radar display system which users could buy. The interested parties should get together on this problem (see point 5 below). The data need to be available, with a cost structure related to value added etc.

5. A portable hydrological radar would be valuable to enable experimentation around the country, outside of coverage of MetService radar. Funding needs to be investigated.

6. A national coordinator needs to be appointed for weather radar and a user group needs to be established. This is an urgent requirement.

7. The MetService initiative to fit the Rapic Weather Radar System to its C-band wind-finding radars is strongly supported (noting that the C-band radars would be repositioned to appropriate locations).

8. The raingauge network is still needed and there are no scientific grounds for reducing it at this stage because of the advent of weather radar. In addition many users won't accept radar as an authoritative source of rainfall data but they do accept raingauges.

9. Radar rainfall accumulations should agree with monthly raingauge data.

Working Group 3.

This group, lead by Professor Chris Collier discussed:

'The use of Weather Radar for forecasting heavy rain in New Zealand'.

The key issues identified were:

1. User requirements are for:
   - spatial distribution of rain
   - lead times up to 24 (36) hours ahead
   - presentation in easy to use format.

2. Dissemination needs to be direct to users from a central location with continuous updates.

3. How the forecasts are updated using radar data.

4. Verification, which needs to be continuous to assess improvements.

5. Research, which needs to be continued.

Specific points about the design of a heavy rainfall forecasting system were:

1. The present system is largely qualitative and too subjective. More objectivity is needed.

2. More accurate quantitative quantitative forecasts are needed.

3. The component parts of a system exist already and are:

   - synoptic understanding
   - mesoscale models
   - satellite data (but no archive of GMS data)
   - radar quality control software
   - RAINSAT

4. The components need to come together in a workstation. At the same time a forecaster must be recognised as an integral part of the system and be allowed to modify generated rainfall fields.

5. A rainfall field must be disseminated to users.

6. A successful system must combine the following:

   At 36 to 24 hours. - Three global models plus synoptic experience.
   At 18 to 12 hours. - Mesoscale models plus satellite input.
   At 9 to 6 hours. - Mesoscale models plus satellite and radar input.
   At 6 to 0 hours. - Radar and satellite inputs plus models.

APPENDIX 1.

NATIONAL SYMPOSIUM ON HYDROLOGICAL APPLICATIONS OF WEATHER RADAR

PROGRAMME

TUESDAY 22 FEBRUARY 1994

0830-0920 Registration and coffee.

0920-0930 Opening address. Dr Neil Gordon, Acting Chief Executive, MetService.

Introduction and scene setting - Chair Dr Neil Gordon

0930-1030 The fundamentals of weather radar operation. Peter Kreft, MetService.

1030-1100 *Morning tea and discussion*

1100-1130 A climatology of New Zealand rainfall. Alaric Tomlinson, NIWA.

1130-1230 The synoptics of New Zealand rainfall. August Auer, MetService.

1230-1400 *Lunch*

Some NZ work and issues about weather radar - Chair Dr Don Thompson

1400-1430 The process of generating severe weather bulletins in NZ. Ian Miller, MetService.

1430-1445 MetService networked radar system. Bob Lake, MetService.

1445-1515 Rainfall modelling. Mark Sinclair, NIWA.

1515-1545 *Afternoon tea and discussion*

1545-1600 Use of radar in a flood forecasting model. S. Ude Shankar and Alistair McKerchar, NIWA.

1600-1615 The Southern Alps Experiment. David Wratt and Roger Ridley, NIWA.

1615-1630 Advantages to ECNZ of improved weather forecasting. Lennie Palmer, ECNZ.

1630-1700 Four or five delegates talk about their interest in, and expectations of weather radar.

1700-1900 ***Icebreaker***

WEDNESDAY 23 FEBRUARY 1994

Today's workshops - Chair Dr August Auer

0830-1000	Workshop 1: Prof Chris Collier, 'The contribution of raingauges, radar and satellites to nowcasting'.
1000-1030	*Morning tea and discussion*
1030-1200	Continuation of Prof Collier's workshop.
1200-1330	*Lunch*
1330-1500	Workshop 2: Prof Geoff Austin, 'The accuracy of rainfall estimation'.
1500-1530	*Afternoon tea and discussion*
1530-1700	Continuation of Prof Austin's workshop.
2000-2300	***Harbour Cruise and Dinner***

THURSDAY 24 FEBRUARY 1994

Today's workshop - Chair Dr August Auer

0830-1000	Workshop 3: Prof Ian Cluckie, 'A radar hydrology perspective : Crucial current issues in radar hydrology'.
1000-1030	*Morning tea and discussion*
1030-1200	Continuation of Prof Cluckie's workshop.
1200-1300	*Lunch*

Working groups - Chair Dr Warren Gray

1300-1430	Four groups to consider the use of weather radar in NZ for: - Urban hydrology (flash flooding) - Major river flooding - Inputs to hydrological models - Radars to supplement raingauges.
1430-1500	*Afternoon tea and discussion*
1500-1545	Group leaders report back.
1545-1600	Summary of the workshops. Gavin Fisher, NIWA.
1600-1800	***Happy hour.***

FRIDAY 25 FEBRUARY 1994

Science day papers

0830-1000	Chair Dr Alistair McKerchar
0830-0855	PMP/PMF modelling for dam design using weather radar. Barney Austin and Ian Cluckie, University of Salford.
0855-0920	Estimating probable maximum precipitation (PMP) using a simple storm model with NWP and Doppler radar data. Chris Collier and Paul Hardaker, METSTAR Consultants, Met Office, United Kingdom.
0920-0940	Acoustic radar estimation of rainfall parameters. Stuart G. Bradley, University of Auckland.
0940-1000	'Radar observations of rain on the sea'. & 'Doppler spectrum of falling raindrops'. Murray Poulter and Murray Smith, NIWA.
1000-1030	*Morning coffee and discussion*
1030-1230	Chair Alaric Tomlinson
1030-1055	Forecasting rain cell location using radar data. Y.B. Pointin, P.J. Bremaud and H.R. Larsen, C.N.R.S. - Universite Blaise Pascal.
1055-1120	Assessing and developing operational radar based rainfall forecasts. Chris Collier, METSTAR Consultants, Met Office, United Kingdom.
1120-1140	The Australian radar network. Bruce Gunn, Bureau of Meteorology, Australia.
1140-1205	Practical issues in the planning and installation of weather radar. Alan Sharp, MetService, and Wayne Miller, Woodward-Clyde.
1205-1230	The use of radar in classification of daily rainfields for improved raingauge interpolation. Dan Harris, Alan Seed and Geoff Austin, University of Auckland.
1230-1400	*Lunch*
1400-1515	Chair Dr Howard Larsen
1400-1425	Satellite rainfall estimates using texture information, validated against radar data. Michael Uddstrom and Warren Gray, NIWA.

1425-1450	The vertical structure of rain and its influence on radar rainfall estimation. Warren Gray, NIWA.
1450-1515	Retrieval of vector wind fields for Doppler radar data. Nik White, MetService.
1515-1545	*Afternoon tea and discussion*
1545-1645	Chair Dr Warren Gray
1545-1610	Areal reduction factors for convective rainfall situations. Alan Seed, University of Auckland.
1610-1620	Vertically pointing radar data in orographic rain. Lief Pigott, University of Auckland.
1620-1630	Measurement of raindrop size distributions and comparisons with raingauge and radar records in stratiform and convective rain. Michael Camilleri, Auckland University.
1630-1645	Closure of the Symposium. Dr Malcolm Grant, Chief Executive, NIWA.

APPENDIX 2

LIST OF PARTICIPANTS

W E Armstrong	Cogito Consultants Ltd	46 Simla Crescent Wellington 4	Ph/Fax (04) 479-7348
August Auer	MetService	PO Box 722 Wellington	Ph (04) 496-9355
Barney Austin	University of Salford	Water Resources Group Civil Engineering Department Salford M5 4WT England	Ph +44 61 745-5000 Fax +44 61 745-5060 Email b.austin@civil-engstudentsSalford.ac.uk
Geoff Austin	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445
Kim Austin	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445
Lynne Barr	Wellington Regional Council	Hydrological Services PO Box 11646 Wellington	Ph (04) 802-0399 Fax (04) 385-6960 Email barr@wrc.govt.nz
Grant Best	Taranaki Regional Council	Private Bag 713 Stratford	Ph (06) 765-7127 Fax (06) 765-5097
Peter Blackwood	Wellington Regional Council	PO Box 11646 Wellington	Ph (04) 384-5708 Fax (04) 385-6960 Email blackwood@wrc.govt.nz
Stuart Bradley	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445 Email s.bradley@aukuni.ac.nz

Michael Camilleri	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445
Ian Cluckie	University of Salford	Civil Engineering Department Salford M5 4WT England	Ph +44 61 745-5000 Fax +44 61 745-5060
Chris Collier	Metstar	The Met Office London Road Bracknell Berkshire RG12 2SY England	Ph 44 344 856 244 Fax 44 344 854 024
Tony Davies	NIWA Climate	PO Box 3047 Wellington	Ph 04 472-9966 Fax 04 496-9414
Glenn Dougal	MetService	PO Box 722 Wellington	Ph (04) 496-9323 Fax (04) 473-5231
Mike Ede	Wellington Regional Council	PO Box 11646 Wellington	Ph (04) 385-5708 Fax (04) 385-6960 Email ede@wrc.govt.nz
Graham Elley	NIWA Kainga	21 Kainga Rd Christchurch 9	Ph (03) 323-8199 Fax (03) 323-7596
Gavin Fisher	NIWA Climate	PO Box 92830 Auckland	Ph (09) 373-7599 Fax (09) 373-7571
Neil Gordon	MetService	PO Box 722 Wellington	Ph (04) 472-9379 Fax (04) 473-5231
Warren Gray	NIWA Climate	PO Box 3047 Wellington	Ph (04) 496-9340 Fax (04) 496-9411 Email gray@award1.kelburn.cri.nz
Bruce Gunn	Bureau of Meteorology	GPO Box 1289K Melbourne Victoria 3001	Ph +61 3 669-4251 Fax +61 3 669-4168
Andrew Harper	NIWA Climate	PO Box 3047 Wellington	Ph (04) 496-9372 Fax (04) 496-9414

Daniel Harris	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445
Bill Hislop	MetService	PO Box 722 Wellington	Ph (04) 472-9379 Fax (04) 473-5231
Graeme Horrell	Canterbury Regional Council	PO Box 345 Christchurch	Ph (03) 365-3828 Fax (03) 365-3194
Tim Hume	Victoria University of Wellington	Institute of Geophysics Private Bag Wellington	Ph (04) 472-1000 Fax (04) 499-4601
Alasdair Keane	Works Consultancy Services	PO Box 12-003 Wellington	Ph (04) 471-7125 Fax (04) 473-1296
Peter Kreft	MetService	PO Box 722 Wellington	Ph (04) 472-9379 Fax (04) 473-5231
Bob Lake	MetService	PO Box 722 Wellington	Ph (04) 472-9379 Fax (w) 473-5231
Howard Larsen	NIWA Climate	PO Box 3047 Wellington	Ph (04) 496-9398 Fax (04) 4969411 Email larsen@award1.kelburn.cri.nz
Darryl Lew	Wellington Regional Council	PO Box 11646 Wellington	Ph (04) 384-5708 Fax (04) 385-6960 Email lew@wrc.govt.nz
Dave McBryde	Hawkes Bay Regional Council	Private Bag Napier	Ph (06) 835-3164 Fax (06) 835-3601
Chris McGeorge	Bureau of Meteorology	GPO Box 727G Hobart Tasmania 7001	Ph +61 02 206-650 Fax +61 02 235-454
Les McGraw	Southland Regional Council	Private Bag 90116 Invercargill	Ph (03) 215-6197 Fax (03) 215-8081

Alistair McKercher	NIWA Freshwater	PO Box 8602 Christchurch	Ph (03) 343-7870 Fax (03) 348-5548 Email aim@sparky.kyle.cri.nz
Ian Miller	MetService	PO Box 722 Wellington	Ph (04) 472-9379 Fax (04) 473-5231
Wayne Miller	Woodward-Clyde (NZ) Ltd	PO Box 821 Auckland 1	Ph (09) 379-3515 Fax (09) 379 7550
John Nicol	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445
Doug Nottage	Tasman District Council	Private Bag Richmond Nelson	Ph (03) 544-8176 Fax (03) 544 7249
Lennie Palmer	ECNZ	Fuel Resource Group PO Box 930 Wellington	Ph (04) 474-2306 Fax (04) 499-0043
David Parkin	Environment Waikato	PO Box 4010 Hamilton	Ph (07) 856-7184 Fax (07) 856-8089
Helen Pearce	Bureau of Meteorology	PO Box 1289K Melbourne Victoria	Ph +61 3 669-4512 Email h.pearce@bom.gov.au
Leif Piggot	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445
Mike Pointer	MetService	PO Box 722 Wellington	Ph (04) 496-9324 Fax (04) 473-5231
Jim Price	Environment Waikato	PO Box 4010 Hamilton	Ph (07) 856-7184 Fax (07) 856-8089 Email jimp@wairc.govt.nz
Tony Quayle	MetService	PO Box 1515 Paraparaumu Beach 6450	Ph (04) 297-3237 Fax (04) 297-3568

Steve Ready	MetService	PO Box 722 Wellington	Ph (04) 472-9379 Fax (04) 471-2078
Tim Rix-Trott	Auckland Regional Council	Environment Land Resources Private Bag 68912 Auckland	Ph (09) 379-4420 Fax (09) 366-2155
John Sansom	NIWA Climate	PO Box 3047 Wellington	Ph (04) 496-9389 Fax (04) 496-9414 Email sansom@award1.kelburn.cri.nz
Alan Seed	University of Auckland	Physics Department Private Bag 92019 Auckland	Ph (09) 373-7999 Fax (09) 373-7445
Alan Sharp	MetService	7 Mcgrath Avenue Paraparaumu Beach 6450	Ph (04) 297-0129 Fax (04) 297-3213
Mark Sinclair	NIWA Climate	PO Box 3047 Wellington	Ph (04) 472-9966 Fax (04) 496-9411 Email sinclair@award1.kelburn.cri.nz
Rod Stainer	MetService	PO Box 722 Wellington	Ph (04) 496-9344 Fax (04) 473-5231
David Stewart	Otago Regional Council	Private Bag Dunedin	Ph (03) 474-0827 Fax (03) 479-0015
Don Thompson	MetService	PO Box 722 Wellington	Ph (04) 472-9379 Fax (04) 471-2078
Stephen Thompson	NIWA Climate	PO Box 3047 Wellington	Ph (04) 472-9966 Fax (04) 496-9414
Alaric Tomlinson	NIWA Climate	PO Box 3047 Wellington	Ph (04) 496-9352 Fax (04) 496-9414
Michael Uddstrom	NIWA Climate	PO Box 3047 Wellington	Ph (04) 472-9966 Fax (04) 496-9411 Email uddstrom@award1.kelburn.cri.nz

Rolf Weingartner	Institute of Geography	Hallerstr 12 CH-3012 Bern Switzerland	
Bill Witham	MetService	7 Mcgrath Avenue Paraparaumu Beach 6450	Ph (04) 297-0129 Fax (04) 297-3213
David Wratt	NIWA Climate	PO Box 31-311 Lower Hutt	Ph (04) 570-1333 Fax (04) 566-6166 Email wratt@award1.kelburn.cri.nz