Agrometeorology in the New Zealand Meteorological Service

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Technical Information Circular 204

UDC 551.586(931)

January 1986

New Zealand Meteorological Service
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WELLINGTON

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1. SUMMARY

This report reviews and discusses agrometeorology both in the wider New Zealand environment and within the New Zealand Meteorological Service. Overall development of agrometeorology in New Zealand has been slow in comparison with some other countries because pastoral farming is less sensitive to weather than cereal cropping and horticulture. New Zealand developments are reviewed in this paper in the context of agrometeorological services and research available in other countries. Requirements of New Zealand agriculture are then discussed, with criteria identified to evaluate new research and services.

Much of the discussion examines possible new activities. These include consolidating the climatological observation network for agriculture, issuing bulletins, making forecasts and providing information in response to enquiries.

The report outlines the meteorological and agrometeorological observations needed to support these activities. Finally, the need for research to allow their development within the New Zealand Meteorological Service is identified.

The main conclusions of this study are:

1. Development of agrometeorology in New Zealand has been generally slow, as during the 1950s and 1960s when pastoral farming was the single important agricultural activity in New Zealand, agrometeorological input was comparatively unimportant. Rapid agricultural growth was achieved instead through improved technology, management and fertiliser application; and through the main pastoral species (perennial ryegrass/white clover) having a wide climatic tolerance.

2. With the recent growth in cereal cropping and horticulture there is increasing production which is very sensitive to weather and climate. This is flowing on as an increasing demand for agrometeorological services and activities.

3. Important agrometeorological research topics were identified during discussions with Ministry of Agriculture and Fisheries (MAF) and Department of Scientific and Industrial Research (DSIR), these include: - agrometeorological assessments of subtropical horticultural crops, identification of the climatic limits of medium altitude hill country pasture, consultation in planning climatic networks for agricultural purposes, measurement and presentation of data more representative of biological responses (such as hourly air and soil temperatures), fine scale mapping of specific climatic and derived elements, phenological observations on important crops (such as apples and kiwifruit), and crop-climate and pasture-climate modelling.

4. The development of new agricultural research and services is dependent on making both general meteorological and specific agrometeorological observations through a more consolidated observation network than is presently operating. Agrometeorological observations allow modelling of crop and animal development and production, with observations of plant development (phenology) being particularly important. For observations to be effective in agrometeorological research they must be standardised and from sites in important agricultural areas. The consolidation of the current network is suggested to include the following sites : - Kerikeri, Ruakura, Te Puke, New Plymouth, Palmerston North, Levin, Gisborne, Havelock North, Nelson, Blenheim, Lincoln, Tara Hills, Clyde, Invermay, Gore and Invercargill.

5. Bulletins, specialized weather forecasts for agriculture, and agrometeorological forecasts are services which could be introduced. Bulletins publicise recent climatic conditions and how these effect pasture, crops and animals. Special weather forecasts for agriculture use conventional meteorological data but include predictions for planting, freeze-damage prevention, control of plant and animal diseases, control of invertebrate pests, application of fertilisers and evapotranspiration advice for irrigation scheduling. Agrometeorological forecasts help predict crop and animal production using current and historical meteorological and agrometeorological data.

6. Operational decisions in agriculture are expected to be increasingly based on agrometeorological information. These are likely to focus on the fine scale mapping of specific climatic elements to weather sensitive horticultural crops. Further research on the quantitative relationships between climate and agriculture is also likely to be required.

7. The development of agrometeorological activities will require research into existing agrometeorological conditions, the agroclimatic requirements of plants and animals and the extent to which these requirements are satisfied. Quantitative relationships between weather and climate, and aspects of agriculture will also require investigation.

8. The potential exists for expansion into many economically, or potentially economically important agricultural services and operations. Identified here are services aimed at pasture, lucerne, wheat, barley, potatoes, apples and kiwifruit. The growth of agrometeorological activities is probably best developed in close collaboration with other government agencies including M.A.F. and D.S.I.R.

2. INTRODUCTION

The WMO describes agrometeorology as being concerned with the interaction of meteorological and hydrological factors, on the one hand, and agriculture in the widest sense, including food crops, animal husbandry and forestry[1] on the other hand. Its object is to discover and define such effects and thus apply knowledge of the atmosphere to practical agricultural use . The zone of interest extends from the soil layer of the deepest plant roots to the higher levels of the atmosphere (WMO, 1981).

Agrometeorology in New Zealand is in many ways still in its infancy. Development has been uneven because the rapid expansion of pastoralism during the 1950s and 1960s was easily achieved with the clearance of bush, very heavy fertiliser application, subdivision and controlled grazing, rather than through climatic management (Philpott, 1977). However, cereal (edible grain) and horticultural crops (those that can be grown in a garden) are far more weather sensitive activities, and their cultivation has required agrometeorological information.

While productive pastoral management can be achieved without a large agrometeorological input, all agriculture to varying degrees, is weather sensitive. The more the agricultural sector is educated to become aware of this, the more reliant it is likely to become on agrometeorological information. However the weather sensitive activities must first be recognised by farmers and their importance evaluated against other factors. The value of agrometeorological information can be illustrated with the two following examples. Studies in the 1970s (Maunder, 1973) suggest an economic benefit of 1% of the total value of agricultural production due to weather forecasts and climatic information ($41 million in 1981). From weather-based predictions of dairy production issued in January 1978 (Maunder 1979b), the predicted drop (compared with the actual drop in production of 8.5 million kg of milkfat) is equivalent to the cargo capacity of about one container ship. The economic implications of this and other agrometeorological forecasts for transportation and other 'beyond farm gate' activities are significant.

By using agrometeorological information and advice, the agricultural sector is able to make decisions on alternative strategies. Already the New Zealand Meteorological Service has most of the essential meteorological data, knowledge and forecasting services to provide a significant agrometeorological

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1. In this report, forestry will not be considered.

service. As the weather sensitive agricultural industry is the basis of the New Zealand economy, agrometeorological services to that sector should be a key area of responsibility for the Meteorological Service. While the Service has statutory authority to provide services for the benefit of all sections of the community, the importance of this industry must be reflected in work and development priorities within the Service. For the successful expansion of agrometeorology in New Zealand, research and development by various scientific groups should be undertaken in close co-operation and collaboration. These wider aims are part of the functions identified in the Meteorological Service strategic planning statement. They include collecting, analysing and archiving meteorological information, providing weather forecasts and other meteorological services, providing meteorological consultancy services and promoting meteorological research.

The following sections outline agrometeorological activities commonly undertaken elsewhere, the present state-of-the-art of agrometeorology within the New Zealand Meteorological Service, and suggestions on a medium-term strategy for agrometeorological research and services within New Zealand.

3. AGROMETEOROLOGICAL SERVICES FREQUENTLY PROVIDED

Agrometeorological services typically provided in many countries (WMO, 1981) include issuing bulletins, issuing forecasts and satisfying a wide range of enquiries.

Bulletins contain user-orientated information and focus on topics such as estimated soil moisture levels, growing degree-days, integrated solar radiation, special phenomena, as well as information on the state and yield of crops and livestock for the various agricultural regions. They can be issued weekly through to seasonally.

Weather forecasts for agriculture vary from general information contained in a conventional regional forecast, to those tailored to specific requirements such as frost forecasting. The general weather services are used as a base to develop specialised forecasting for agriculture. Examples of products that might be developed include forecasts for haymaking, disease and pest outbreaks, timing of fieldwork operations, crop yield and soil moisture.

Servicing of enquiries covers a wide range of applications. For example these can be related to planning for the development of agricultural regions in the short, medium or long term. On long time scales agroclimatic information deduced from macroclimatic data enables suitability of a crop or activity to be assessed for an area. This may be to justify the capital investment necessary for horticulture, or the exploitation of an area for livestock. Studies such as these require a knowledge of the crop's response to climate, and how climate affects its economic viability. Agroclimatic suitability is often mapped to form a useful tool in land-use decision making. Maturation dates and yields of crops are affected by water stress and heat accumulation. To make this information easily accessible by farmers a seasonal forecast or list of probabilities (such as frost risk, and heat accumulation of phenological stages) can be issued to enable planning of medium term management strategies over several months. Such planning involves evaluation of climatic limitations, mesoscale agroclimatic surveys for cereal and horticultural crops and improvements to production through irrigation, shelter, shade and crop cover, and averting dangers to production. In assessing weather risks for agriculture, factors that can be examined include specific weather phenomena, dates of last and first air frosts, irrigation scheduling, evaluation of wind hazards, and spring soil moisture and yield.

Development of the relevant agrometeorological services for crop and animal production requires research, and in turn data on existing agrometeorological conditions . Once the response of crops to weather and climate is understood, observations on crops and livestock enable the agrometeorological requirements of these activities to be gauged.

4. AGROMETEOROLOGY IN THE NEW ZEALAND METEOROLOGICAL SERVICE

Agrometeorological studies in the New Zealand Meteorological Service started with the work of Kidson (1929) who examined weather and wheat yields. During the 1930s work continued in defining basic climatology (e.g. Kidson, 1936; Seelye, 1940). Since 1945, the effort in agrometeorology has expanded, initially with the establishment of a climate network in agricultural areas, then with research relating outbreaks of facial eczema to weather (Robertson, 1968). Subsequent research has included water budget modelling for soil moisture estimation (Gabites, 1960; Coulter, 1973) and agroclimatic/economic models and indices (Maunder 1974, 1977b). Appendix A contains a list of N.Z. Meteorological Service agrometeorological publications. A useful review of agrometeorology to 1975 is contained in Coulter (1975).

Presently, the New Zealand Meteorological Service provides general public forecasts through the news media, but does not make routine weather forecasts exclusively for agriculture. However, there are some special weather forecasts for agriculture such as those issued to advise frost danger in Central Otago in the spring, and the forecasts for haymaking made on request. Agricultural aviation forecasts are also made in the Waverley area, and some pest destruction boards are issued with forecasts.

From a network of approximately 340 climate stations, data is provided for all meteorological services, including agriculture. As yet no network of special agrometeorological stations recording agroclimatic data exists, though some climate stations have been established to service agricultural requirements. Some of these have additional instruments provided by DSIR and MAF for experimental work.

The climate station distribution with altitudes is shown in Table 1.

Table 1. Altitude of Climate Station Network April 1985

ALTITUDE (metres)	NORTH ISLAND Stations No.	%	Land Area %	SOUTH ISLAND Stations No.	%	Land Area %	TOTAL Stations No.	%	Land Area %
under 100	120	63.5	27.8	65	42.8	13.7	185	54.2	20.8
100 - 250	29	15.3	26.6	44	28.9	15.9	73	21.4	21.3
250 - 500	21	11.1	26.1	26	17.2	20.3	47	13.8	23.2
501 - 750	10	5.3	12.8	7	4.6	17.1	17	5.0	14.9
751 - 1000	7	3.7	4.2	6	3.9	11.5	13	3.8	7.8
over 1000	2	1.1	2.5	4	2.6	21.5	6	1.8	12.0

The existing network is adequate for broadscale delineation of the climate in lowland areas. However, while 58% of New Zealand's land area lies above 250 metres, only 25% of the current climate network provides for this sector. This means that medium and high altitude hill country lacks even a general coverage. To help correct this, extension of the network into more remote areas is planned with the installation of automatic weather stations and environmental data recorders.

A few rainfall stations make unsystematic phenological observations. Summaries of derived data and computer printouts of climatic factors gathered by these stations give users information, including simple water balance analyses of rainfall data, and degree-day and winter chilling accumulations. To improve usage of the information collected, much of this data is currently being mapped. A list of specific agriculturally oriented data is given in Appendix B. This excludes the many publications and printouts of basic data summaries.

Research and development for routine operational services has concentrated on evapotranspiration estimates and weighted weather indices. To enhance present services a Li-cor solar radiation network is currently being installed and a daily climate message is being implemented based on climatological data from a number of stations. With the cooperation of MAF and DSIR additional data is gathered from other climate stations. Evapotranspiration is then calculated and transmitted back to the climate stations and the information then published in the appropriate newspapers and broadcast on local radio stations. In this way evapotranspiration estimates can be used for irrigation scheduling. Once the daily climate messages are available, issuing of other real time agriculturally oriented data such as growing degree-days will be possible.

Weighted weather information allows special assessments to be made for agricultural operations. Weighting is made according to the distribution of the item of interest, such as dairy cattle, sheep, beef cattle , vegetable growing areas, etc. By weighting the weather data, climatic anomalies of rainfall and temperature can be compared for various populations. Weighted weather data is produced in real time for about 120 populations/commodities. This information is issued three times a week as bulletins to the MAF Media Link service. Weighted weather data and soil moisture estimations are used to make weather-based predictions to various agricultural agencies. These include routine forecasts of dairy, meat and wool production, and lambing percentages (Maunder and Davison, 1980).

One special disease assessment service has been developed. In the event of an outbreak of foot and mouth disease, an operational service is able to indicate the windborne dispersal of the disease virus.

In the area of agrometeorological planning only two publications have been issued. One deals with the climatological aspects of grape growing in New Zealand, and the other (in association with MAF and DSIR) matches horticultural crops and climates in the lower North Island.

Currently satellite imagery is being archived for the lower North Island (data from a larger area cannot presently be stored because of limited computer facilities). The satellite radiometers produce a derived index related to the amount of photosynthetic activity, the "greeness" index. This index is being related to the rate of pasture growth in two pastoral areas, one in the Manawatu and the other in the Wairarapa. With further development it may be possible to use satellite imagery operationally to provide an index on the state of pasture (Taylor, Kidson and Dini, 1985).

5. REQUIREMENTS OF NEW ZEALAND AGRICULTURE AND THE ECONOMY

In 1983 income from agricultural products accounted for 61% of New Zealand's export earnings (Monthly Abstract of Statistics, April 1984). By far the largest proportion (54%) was from the pastoral farming products of meat, wool and dairy products while fruit and vegetable products were very much lower(3%). Expressed as a percentage of gross agricultural output (in $ value) the pastoral sector accounted for 75% of production, cereal crops 5%, fruit 5% and vegetables 4% (New Zealand Yearbook, 1983). Pastoral farmers in areas suitable for cereal and horticultural crops have often been slow to change from pasture. According to Kerr (1984) one growth area in New Zealand agriculture during the next decade is expected to be in cereal cropping and horticulture.

Presently, there is rapid growth in the acreage of subtropical fruit in northern New Zealand. However, climates in the area are marginal for successful growing of some of these crops, and climatic suitability needs to be established. Current economic pressures are also demanding a higher net return per hectare, so in the pastoral sector there is an impetus to increase productivity. The greatest opportunities here, lie in the grazing of medium altitude (500 metres - 1000 metres) hill country, which makes up a reasonable proportion of South Island pastoral land. Expansion of pastures to these higher elevations with increased stocking rates requires trials of new pasture species and stock management practises. The ultimate factor for hill country production is the limit that climate places on pasture growth and economic yields.

Requirements for further agrometeorological research were ascertained during visits to MAF and DSIR research centres and a full summary of their needs is given in Salinger (1985). The Meteorological Service is able to fulfill many requirements for climate data but is hampered by sparse data collection at medium and high altitude locations. Demand for solar radiation data is high, and the installation of the Li-cor radiometer network over the next year or so is expected to satisfy this requirement. It is desirable that potential users be consulted at an early stage for best instrument siting. More hourly air and soil temperatures in tabulated format, from representative locations are also required. In addition consideration must be given for presentation of data in a form that is directly applicable to the user (for example, soil moisture deficits rather than rainfall; probability distributions rather than means; level and duration analyses for heat units). The latter example has implications for timing of crop development, crop chilling, frost protection, glasshouse heating, etc. Of agriculturally oriented information, the greatest demand was for evapotranspiration and soil moisture information, either by direct or indirect measurement techniques. Other important products were identified as frost risk analyses and heat unit data.

It is important farmers use both basic and derived agrometeorological data in their land management decisions. In working towards making this information available, largescale maps of derived indices are planned - including factors of degree-days, chill units, frost risk and potential evapotranspiration. However, they are only useful as general background to an area, and cannot be used for decision-making on an individual farm level, where the microclimatic, and therefore the potential land use may be quite different from the surrounding area. Where the climate of a region is generally unsuitable for a crop, small pockets of land where microclimate conditions are favourable have increased importance. These very localised climates, resulting from the rugged terrain of New Zealand require improved description. Both MAF and DSIR stressed the importance of developing methods of measuring and mounting surveys to determine local microsite variations. (Because the country is windy they also emphasised the role of shelter on local microclimates).

As yet no organised phenological observations are made in New Zealand. These observations link plant growth and development with climate, and are therefore essential for crop-climate modelling and planning. A strong need was expressed by MAF and DSIR for more information in this area. Pasture modelling work has been researched by a few MAF scientists but there is also plenty of opportunity for expansion of this work. Full consideration should also be given to requirements from producer boards, farmers, transport operators and marketing companies.

6. FURTHER DEVELOPMENT OF AGROMETEOROLOGICAL ACTIVITIES IN THE NEW ZEALAND METEOROLOGICAL SERVICE

Before outlining the goals that agrometeorological activities might achieve within the Meteorological Service it is useful to consider a few guideline criteria to identify priorities.

i) Agrometeorological services should be aimed at improving knowledge and aiding the prediction of growth, development and yields in plant and animal production, to reduce uncertainty in agricultural planning.

ii) The services or research should have wide application. Sometimes studies for research and development may be run on a regional or local basis to elicit information as a trial or demonstration experiment. In this case the results or methodology should still have national applicability and use.

iii) The studies and application of agroclimatic information should be recognised for their economic significance.

iv) The activities should be compatible with the functions of the Meteorological Service described in the Service's strategic planning statement.

Agrometeorological operations fall into three categories: issuing of bulletins, issuing forecasts, and servicing enquiries from all parts of the agricultural community. Before introducing new services, research and assessment of economic benefits and/or market research is necessary to ensure the above criteria are met. The following recommendations are made in the context of a medium to longer term strategy and should first undergo a process of evaluation.

- Observations

In agrometeorology two types of observations are distinguished (WMO 1981). Meteorological observations are those of the physical environment from the top of the troposphere down to the soil surface and a few metres below. Agrometeorological observations are those of crops, pastures, animals, and pests made to explain relationships between weather and climate and many aspects of agriculture, and to monitor the state of crops and animals.

As already noted, observations of both meteorological and agrometeorological elements are necessary for the development of agrometeorological services. They allow agrometeorological planning, forecasting and research; but because this data have not been available historically in New Zealand, conventional meteorological and climatological data have been used to satisfy information demands from the agricultural sector.

Agricultural meteorology needs to examine every aspect of local and regional climate to provide data for assessing actual and potential crop and animal production. The World Meteorological Organisation (WMO, 1981) has recommended standard environmental observations for this purpose. However, although these measurements are standard, they may not be the most relevant parameters to assess plant growth and development. Observation techniques are best developed knowing how the data will be used, and the plant's time response.

Agrometeorological observations and environmental inputs to agronomic research have recently been summarised by government agencies (MAF, 1984). The observations can either be a qualitative or quantitative measure of plant or animal response to weather conditions. They may be made for specific research projects or used routinely in a network of agrometeorological services. Quantitative observations are very specific while qualitative are more general. The number and type of observations performed at a particular station depends on the agricultural activities in the area.

Meteorological data alone has limited application to agriculture because it allows only a small number of agrometeorological activities to be developed. For agricultural meteorology it is necessary to make simultaneous observations of the effect of climate on both plants and animals. By comparing the two types of data, it is possible to determine the effect of weather and climate on the growth and development of crops and animals, and allow better development of agrometeorological services.

New Zealand is one of a few countries not making agrometeorological observations as defined by the World Meteorological Organization. Of 60 countries responding to a WMO questionnaire on agrometeorological observations, only five (including New Zealand) indicated that no observations on a regular basis were collected (the others were Australia, Brazil, France and the United Kingdom). Given the importance of agriculture in New Zealand, and the strong influence of weather and climate, relevant observations should commence in key areas to enable development of agrometeorological services. This would be an extension to the services already provided by the New Zealand Meteorological Service.

A sound agrometeorological data base is required for agrometeorological activities and it is recommended that the climatological network be consolidated for the purposes of recording meteorological and agrometeorological data. Details on the method of consolidation, evaluation of locations and types of observations required are contained in Appendix C.

- Agrometeorological Bulletins

The purpose of agrometeorological bulletins is to advise the agricultural community on how the current growing season is developing. Bulletins contain information such as accumulated growing degree-days, current soil moisture status and observations on the state of pastures, crops and livestock. Compiling could take place at a central location using data gathered at agrometeorological stations. It is recommended the present service be expanded to include bulletins for all agricultural districts, containing full agrometeorological information and issued weekly to all news media (radio, videotex, teletext and newspapers). Further details are given in Appendix D.

- Forecasts

Forecasts for agriculture can either be derived from conventional weather forecasts or be specially designed agrometeorological forecasts (WMO 1981). The World Meteorological Office has given the following definitions:

- Special weather forecasts for agriculture are forecasts of weather elements affecting farm operations based on conventional meteorological data and current climate for agriculture.

- Agrometeorological forecasting is concerned with the assessment of current and expected crop and livestock performance including dates of development stages (especially maturity), yields and other factors affecting production patterns.

Forecasts for agriculture are derived from synoptic reports and daily climate data. Current agricultural operations are dependent on accurate forecasts of meteorological elements to provide assistance in making farming decisions. The requirements for these forecasts vary according both to the season, and the farming activity. To accommodate this fluctuating demand, small computers planned for regional weather centres could be used to produce forecasts.

Agrometeorological forecasts use past and present meteorological data (and not their values extrapolated into the future) to predict future crop and animal performance. Methods are based on :

(i) the continuation of the current inertia(2) of crops and animals and their environment (the general climate of the area)

(ii) the dependence of the present inertia on past and present weather conditions.

Many countries find these forecasts are presently the most important means of servicing agriculture and planning agricultural production. Agrometeorology advisory services assist the agricultural sector to make the best use of climate data for economic operation, to stabilise yields and maximise animal production. It is recommended that special weather forecasts for agriculture and agrometeorological forecasts be considered as either routine or special services. Suggested types of forecasts and more details are given in Appendix E.

- Enquiries and Applications

Enquiries and applications for agrometeorological services are likely to be the areas of greatest demand. Subjects for further investigations for long term planning applications include pasture production on medium altitude hill country; kiwifruit and subtropical fruit assessment in northern areas; stone, pip and berry fruit assessment in the central North Island, Marlborough and Canterbury; and cropping in Central Otago. Additionally, fine scale mapping of specific climatic elements which affect the selection of cereal and horticultural crops in established farming areas is very important. Medium term planning (the effects of seasonal and interannual variability on development and production), short term operational decisions and relationships between climate and agriculture (for instance, in crop-climate models) also require investigation. It is suggested that research to assist a few

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(2) The current inertia refers to the current crop or livestock.

agrometeorological enquiries and applications be considered. Some enquiries would benefit from collaborative input from the Meteorological Service, MAF and DSIR.

- Research

For the suggested agrometeorological activities considerable research is recommended. Much of this research relies on the agrometeorological observations outlined in section 6.1 and Appendix C. Initially research should be aimed at the most important agrometeorological activities which could supply services and advice on pasture, lucerne, apples and kiwifruit. Development of research needs to be by a series of phases. These would be to assess existing agrometeorological conditions, determine agrometeorological requirements of crops and livestock, and then examine the extent to which these requirements are satisfied. Modelling work is also required to describe the quantitative relationships between climate and agriculture.

7. CONCLUSIONS

New Zealand agrometeorology has made a solid start with a good network of basic observations and services. However it is now appropriate to expand both operational services and applications. To achieve this, agrometeorological observations must be introduced at a number of stations and considerable research will also be required. Resources in the New Zealand Meteorological Service are not large, therefore observations and services would be most effectively developed in collaboration with MAF and DSIR, targeted at the most economically important agricultural activities. Examples of these, based in order of annual production, are: pasture, lucerne, wheat, barley, potatoes, apples, kiwifruit and the introduction of subtropical horticulture.

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APPENDIX A

New Zealand Meteorological Service Agrometeorological Papers

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APPENDIX B

Agricultural Oriented Publications and Data of the New Zealand Meteorological Service

Data Publications

New Zealand Meteorological Service Miscellaneous Publications:

No. 150. Sunshine normals 1941 to 1970.

No. 158. Temperature frequencies for selected New Zealand stations (Daily, means, maxima, minima).

No. 159. Average degree day tables for selected New Zealand stations.

No. 173. An air frost chronology for New Zealand: Statistics of first and last air frost dates, and of air frost free duration in New Zealand.

No. 178. Earth temperature normals, 1951 to 1980.

No. 183. Temperature normals 1951 to 1980.

No. 185. Rainfall normals for New Zealand 1951 to 1980.

Data Computer Printouts

- Mean daily insolation calculated from sunshine duration, yearly values.

- Calculated solar radiation for the period 1941 to 1970.

- Frequency percent and cumulative frequency percent N days radiation. Average radiation in langleys. Month, year and seasons. Extreme max. and min. N = 1 to 100 in various increments. Auckland Airport, Kelburn and Invercargill only.

- Growing or cooling degree days above and below base temperature °C. Based on 1941 - 1970 normal. Normal degree day totals per month/season/year. Normal and standard deviation.

- Growing degree days, monthly totals. All climate stations except synoptic stations. Base 5°C.

- Growing degree days, accumulating totals. All climate stations except synoptic stations. Base 5°C.

- Degree day totals of daily mean temperatures above/below base T °C. Month, year, seasons, warm and cool seasons.

- Hourly chill units estimated from daily maximum/minimum temperatures.

- Wind rose data. Frequency tables, North and South Island.

- Drought and dry spells to present. Drought (over 14 days with no rain).Dry spell (over 14 days less than 1.0 mm daily).

- Daily water balance using soil moisture capacity of 75 mm. Monthly/annual totals. Thornthwaite PE. Summary, averages and frequencies.

- Daily water balance using soil moisture capacity of 75 mm. Monthly/annual totals. Penman PE for various periods. Summary, averages and frequencies.

- Penman PE Monthly/yearly averages.

- Daily water balance using various soil moisture capacities. Monthly/annual totals. Penman PE. Summary, averages and frequencies.

- Penman evaporation saturation deficit. To present. Mean and standard deviation.

- Penman evaporation, open water to present. Mean and standard deviation.

- Penman evaporation, Penman potential evapotranspiration to present. Mean and standard deviation.

- Penman evaporation, Priestley-Taylor energy term. To present. Mean and standard deviation.

- Summary sunken and raised pan evaporation, mean, extremes and standard deviation.

APPENDIX C

Agrometeorological Network and Observations

Section 6 recommended consolidating the climatological network to record meteorological and agrometeorological data for agriculture. This section proposes the types of meteorological and agrometeorological observations for such a consolidated network along with their possible locations. These should be reviewed by relevant personnel from MAF, DSIR and universities, then implemented with the following recommendations.

OBSERVATIONS

Appropriate locations for the agrometeorological network could be at MAF , DSIR and university research centres in addition to Meteorological Service branch offices. This would allow the New Zealand Meteorological Service expertise in maintaining regular networked recordings to be combined with the experience of staff at agricultural research centres, in making observations. Locations for observations should be areas representative of agriculture. They could possibly include:

Kerikeri Horticultural Research Station (MAF)
Te Puke (DSIR)
Ruakura (MAF)
New Plymouth Airport(MET)
Palmerston North (DSIR) or Ohakea (MET)
Levin (MAF)
Gisborne (MET)
Havelock North (DSIR)
Nelson Airport (MET) or Appleby (DSIR)
Blenheim (Marlborough Research Centre)
Lincoln College
Clyde (DSIR)
Tara Hills (MAF)
Invermay (MAF)
Gore (DSIR)
Invercargill Airport (MET)

Many of these locations already have climate stations which were established primarily to service agriculture. However, before determining where best to make agrometeorological observations, an assessment should be made of environmental gradients across key areas. Initially it may be prudent to attempt agrometeorological observations at two locations (e.g. Ruakura and Lincoln College), concentrating on pastures and kiwifruit. Agricultural meteorological stations should be regarded as complementing observing stations of other networks, rather than forming a separate network. As far as possible each distinct agricultural region should be represented by at least one agricultural meteorological station.

- Meteorological Observations

Listed below are standard observations which the World Meteorological Organization recommends (WMO, 1981) to evaluate actual and potential crop and livestock production. Maps of the sites where some of these parameters are measured in New Zealand are contained in Figures 1 - 7. Evaluation of how the data will be used, and the plant's time response is necessary. For example, two growing seasons may have the same average temperature but one season has low variability. The ultimate yield will be quite different because of the plant response to variability, and the different time periods at critical temperatures. Air temperature at screen height is only a proxy for plant temperature; perhaps the relevant measurements are those at the top of the crop canopy, and 1 or 2 cm in the soil at root level. Therefore the relationships between standard observations and derived variables need continual evaluation.

- Solar Radiation and Sunshine

These measurements are used in calculating upper limits on potential and actual biomass production and growth (Jamieson and Wilson 1984, Wilson and Jamieson 1984). They are also used in determining evapotranspiration rates. Additionally the length of photoperiod is used as a developmental control.

- Temperature

Various temperature parameters determine plant development and growth rates, and length of the growing season. Pest and disease development are also strongly correlated to temperature parameters. Elements measured should include air (screen) temperature, grass minimum, soil temperature at depths of 5, 10, 20, 30 and 100 cm, hourly air and 10 cm soil temperature and observations of hoar frost. Temperature measurements at levels where heat is critical for growth and development such as meristem and leaf heights should also be considered.

- Moisture

Moisture availability largely controls plant growth and transpiration. There are several aspects of moisture and water budget that need monitoring. These include atmospheric humidity and vapour pressure, dew, precipitation, evaporation and soil moisture. Soil moisture monitoring is especially important as low amounts arrest plant growth. However, because of the varying soil structure resulting in differing available water capacities, soil moisture shows large spatial variability.

- Wind

Wind exerts an important influence on evapotranspiration. The most appropriate measurement for this purpose is that of windrun. Additionally, wind hazard can cause much mechanical damage to plants, and cold (or heat) stress in animals.

- State of Ground

Whether the ground is dry, wet, snow covered, or frozen, is important in evaluating possible cultivation, especially cropping, and resowing of pasture.

- Agrometeorological Observations

These observations are divided into three general areas - phenological (plant development), state of the crop (health) and pasture observations. They should be made at, or close to, climate sites in representative agricultural areas. It may be necessary to only perform two of the following observations at one station, while another may carry out many more.

- Plant Development (Phenology)

As plants advance through their life cycle from seed germination to maturity (and the formation of new seeds), they progress through different developmental phases which show distinct external changes. These developmental phases are a result of environmental conditions and are called phenological phases (or stages) with the observations being called phenological observations. Plant development is affected by several meteorological factors of which air and soil temperature and photoperiod are the most important. The beginning and end of the phases are used to calculate rates of plant development. The data can then used for both operational agrometeorological forecasts, and research work. Phenological observations can be made with varying details and accuracy. There is a danger that masses of data could be gathered which do not relate to any specific purpose. If this is only gathered in initial pilot projects, later evaluation of these observations linking crop-climate relationships and development models, and demand for information in agrometeorology bulletins and forecasts should then determine operational requirements. It is suggested that phenological observations be made for apples, kiwifruit and grapes using appropriate developmental stages.

- State of Crops and Livestock

The state of plants and animals is also determined by weather and climate regardless of their speed of development. Plants can be in different phenological stages because of favourable or unfavourable weather conditions. The observations that should be carried out are:

(i) State of crops and animals
(ii) Density of sowing area and animals
(iii) Height of plants
(iv) Damage due to adverse weather conditions (such as drought, hail, heavy rain, high winds frost and extreme temperatures)
(v) Damage due to pests and diseases
(vi) Extent of weeds
(vii) Crop yield and animal production.

- Observations on Pasture

Agrometeorological observations on pastures and animals (for example quality and quantity of wool, animal weights, etc as in Meat and Wool Board sample farms) should be implemented. The observational programme should include:

(i) Phenological observations
(ii) Biomass productivity (vegetative mass)
(iii) Height of pasture
(iv) Damage caused by adverse weather conditions
(v) Damage caused by pests and diseases
(vi) General state of pasture

- Method of Consolidation

- Evaluation and Review

To evaluate the agrometeorological plan above , staff in MAF, DSIR and other institutions involved in agricultural science should review it by: -

(i) Circulating the proposal to appropriate DSIR, MAF departments and agricultural institutions
(ii) Convening a meeting of representatives from MAF, DSIR and agricultural institutions at the Meteorological Office in Kelburn to discuss the proposals.

From the meeting a final selection of appropriate sites and observations for a network of agricultural meteorological stations can be assembled.

- Implementation

Implementing the plan means installing instruments in formally established agrometeorological stations which in many cases will be existing climatological stations. However it will be important to redesignate these as agrometeorological stations and to stress to the observing organisation that the site should be at a key location in terms of national importance to agriculture. Hopefully, by having an agrometeorological designation there will be stability of observations from that site, and a commitment to long-term monitoring. The commitment to permanence is very important for a variety of reasons. When microclimatic surveys of an area are made the data can only be calibrated against a longer term base station to obtain local comparisons and longer term averages. In addition, recent studies indicate that climate is not necessarily stable. To detect any climatic fluctuations and trends, long term monitoring of a regional climate from one site is essential. Designation, expansion of instrumentation and supervision of the agricultural meteorological network should be the responsibility of the New Zealand Meteorological Service. Stations should be inspected frequently enough to check whether exposure has changed significantly and to ensure observations conform to appropriate standards.

APPENDIX D

Agrometeorological Bulletins

Section 6 recommended the expansion of real-time agricultural weather bulletins issued by the Meteorological Service. Currently weekly bulletins of rainfall, temperature and growing degree-day data are issued for specific locations along with nationally weighted data issued for specific economic sectors. The bulletins are distributed to MAF in Wellington and Meteorological Service branch offices.

The expansion recommended is for a weekly bulletin with full agrometeorological information, compiled on a regional basis for the agricultural districts. The regional bulletins could emphasize aspects important to that district, allowing contents and format to vary in each area.

The information is to help farmers make management decisions based on the status of the current growing season. Presently the number of climate stations providing data to Kelburn for the daily climate message is increasing. This allows calculation of solar radiation, potential evapotranspiration, soil moisture, accumulated heat units and other agrometeorological information on a real time basis. The weekly bulletin would be a full agrometeorological report and should be published in real-time to be of maximum use in farming operations. Published information could include data on solar radiation, soil moisture, runoff, photoperiod, chill units and air frost incidence. Additional data such as standard climatological observations (with departures), maps of agriculturally important indices (e.g. growing degree-days, soil temperature and moisture) and information on the state of pastures and crops in various districts could be included as practicable. Presently DSIR at Havelock North (Table 2) issue a weekly agrometeorological bulletin in the Hawke's Bay Daily Telegraph.

Table 2. Agrometeorological Summary published in the Hawke's Bay Daily Telegraph

The following data are a guide to the status, development, and trend of the current growing season. The information is from the climatological station at DSIR, Havelock North, and covers the six days up to 9am, Tuesday, February 5, 1985.

	This week	Difference 1983	from: Ave
(1) SOLAR ENERGY (mean daily)			
Incoming radiation (watt-hours per sq m):	7047	+2036	-
Sunshine (hours):	10.5	+5.5	+3.6
(2) WIND (km)			
Mean daily windrun :	127	+5	-13
Highest 1 day windrun :	168	(Feb 2 '85)	
(3) HEAT Air Temperature at 1.3m (°C)			
Mean daily maximum :	25.5	+3.3	+1.6
Mean daily minimum :	11.3	-0.5	-0.9
Coldest screen minimum this week :	5.0 (Feb. 4)		
Degree-days above 10 °C accumulated from Dec.1 (deg.days):	612	+220	+130
Grass Soil Temperatures (°C)			
Mean daily grass minimum :	6.5	-5.1	-2.4
Coldest grass minimum this week :	2.4 (Feb. 4)		
Mean daily 10cm depth (9am) :	20.4	+0.8	+1.6
Mean daily 30cm depth (9am) :	23.1	+2.4	+2.2

(4) WATER BALANCE (mm)	This Week	This Month	Feb Ave
Rainfall total :	-	-	54
PET* total :	16.3	16.3	116
Net gain (+) :	-	-	-
Net loss (-) :	16.3	16.3	62
Forecast PET next week (mm/day) :	4.8		

(*PET = potential evapotranspiration)

It is proposed that the Meteorological Service at its Head Office in Kelburn prepares an agrometeorological bulletin for weekly publication to all media (newspapers, radio, videotex and teletext) for each of the key agricultural areas. With further evaluation this service could be expanded to other agricultural areas. The central preparation of bulletins ensures format uniformity and rapid computer dissemination.

APPENDIX E

Forecasts

INTRODUCTION

Section 6 recommended the consideration of special weather forecasts for agriculture and agrometeorological services to be introduced either as routine or special services.

In New Zealand, the pastoral feed crops - grass, clover, lucerne, turnips and brassica winter feeds, are the most important plants grown for input into meat, wool and dairy production. Therefore concentration should be on forecasting the growth, development and yield of these. Table 3 lists crops of importance to the New Zealand agricultural economy in terms of production.

Table 3. Crops of importance to New Zealand agriculture in order of production (80/81 season in thousands of tonnes)

1. Pastoral Sector	2. Cropping Sector	3. Horticultural Sector
Grass	Wheat (325)	Apples (242)
Clover	Barley (271)	Potatoes (208)
Lucerne	Maize (152)	Vegetables (152)
Winter feed brassicas	Oats (45)	Onions (66)
		Peas (54)
		Stonefruit (34)
		Citrus (30)
		Kiwifruit (25)
		Pears (19)
		Berryfruit (10)
		Subtropical (3)

The following sections deal with the various types of forecasts for further consideration.

SPECIAL WEATHER FORECASTS FOR AGRICULTURE

- Planting Forecasts

Seed germination and effective fertiliser application are dependent on soil temperatures above a critical level which varies with the species. Nitrogen fertilisers to be effective, also require the soil moisture level not to be excessive. Forecasts, and soil temperature monitoring before and during the planting season assist in making decisions on seed sowing and fertiliser application. They also help prevent the expensive replanting of seed if cold and wet soil conditions occur. Districts where crop plantings and fertiliser applications are extensive enough to warrant such a forecast include: Waikato, Taranaki, Manawatu-Horowhenua, Gisborne, Hawkes Bay, Wairarapa, Nelson, central Marlborough, Canterbury and Southland.

- Freeze-damage Prevention Forecasts

These are needed daily during the production period in areas subjected to freezing temperatures. Freeze-damage prevention forecasts provide the farmer with information to plan operations which will prevent freeze-damage. One suggested service is to provide lowest temperature data at key stations in relevant districts, and a best estimate of times and durations of below freezing temperatures. As New Zealand has a maritime climate the probability of unseasonal frosts is relatively high. Information is needed most at the critical stages of plant development - for fruit it is in spring to early summer when damage occurs to buds and young fruit; for frost sensitive crops and some fruit it is in autumn when frost damages the maturing or mature crop. The growing horticultural, and especially subtropical horticultural sector is particularly prone to unseasonal frost, principally in autumn. Key stations for frost forecasting include: Kerikeri, Whangarei, Kumeu, Pukekohe, Hamilton, Tauranga, Te Puke, Whakatane, Gisborne, Hastings, Levin, Otaki, Masterton, Nelson, Blenheim, Christchurch, Hororata, Kurow, Cromwell, Alexandra and Roxburgh.

During the season when frost is likely to damage sensitive crops, a frost warning service could be implemented. The frost risk or minimum temperature predictions at specific key locations could be recorded on a dedicated branch office ansatel. If a frost is predicted, then growers can telephone the branch office concerned for more details. A knowledge of temperature departures of a particular farm along with those of the key station, would enable a prediction for that specific location.

- Control of Plant and some Animal Diseases

Once vegetation is wet the rate of plant disease development is approximately proportional to the increase in temperature. To develop more efficient use of chemical sprays for disease control, prediction of the potential for disease outbreaks could be made from real-time climate data. There are currently many biological models which predict development of plant diseases and the addition of real-time meteorological data into these models could allow accurate prediction of suitable conditions for disease development and the potential severity of any outbreak (Young 1975).

Districts where forecasts for disease outbreaks could be considered are those with warm humid weather in the summer and autumn. Important areas include Northland, Auckland, Waikato, North Taranaki and Bay of Plenty. In certain summers such forecasts could be considered for Gisborne, Hawkes Bay, Nelson, Marlborough, Canterbury and Southland.

- Control of noxious Invertebrate Pests

As with plant and animal diseases there are principal meteorological factors which control insect occurrence, distribution and numbers (Lowe,1966; Rohitha and Penman, 1983). Factors such as temperature and humidity either foster or suppress insect life, and strong winds control migration. Biological computer models of insect and plant behaviour and interaction can help determine the timing and severity of economically damaging outbreaks of pests such as grass grub, nematodes, codling moth and aphids. The prediction of such outbreaks allows farmers to plan pesticide application strategies to intercept and eliminate pest infestations.

- Application of Agricultural Chemicals

Chemicals may represent a significant proportion of a farmer's total cash outlay in any given season. The cost can be minimised with application during favourable weather conditions. Effective application of chemicals is determined by temperature and rainfall in the 24 hours following application (temperature controls effectiveness, and rainfall dilutes or washes off spray), as well as wind speed and direction. Given the widespread application of chemicals in New Zealand such forecasts could be developed for economically significant agricultural districts such as Waikato, King Country, Taranaki, Manawatu, Wairarapa, Nelson, Canterbury and Southland.

- Evapotranspiration advice for Irrigation Scheduling

Irrigation is costly both to the Ministry of Works and the land owner. At present government funds 35% of irrigation headworks and off farm structures, which in 1981/82 cost $40 million (NWASCO, 1983). Under-use of irrigation can result in crop and livestock losses whereas over-use is both expensive and detrimental to soil structure, crop and pasture growth. An example can be seen in the Waiau plains where gross over-use caused waterlogging of the soil. Estimates of consumptive use can be made from the free water loss of a Class A evaporimeter and calculations based on Penman evapotranspiration formulae. The estimates of evapotranspiration for the previous 24 hours can be obtained from actual values of free water evaporation and other climate data recorded, while the losses for the next 24 hours must be forecast. Already evapotranspiration estimates for the previous day are being published in Christchurch, Timaru and Nelson and expansion is planned with the implementation of the daily climate message. Evapotranspiration combined with rainfall probability forecasts should be an additional product. The areas where such a service is warranted include cereal cropping areas, horticultural areas and lowland pastoral areas that have high soil moisture deficits during the production period. These areas are : Kerikeri, Whangarei, Waikato, Bay of Plenty, lowland Taranaki, Gisborne, Hawkes Bay, Manawatu-Horowhenua, Nelson, Wairau Valley, Canterbury Plains, Waitaki Valley, Central Otago valleys and the Southland Plains.

AGROMETEOROLOGICAL FORECASTS

Discussed below are three examples of agrometeorological forecasts important to New Zealand.

- Phenological Forecasts

Almost every agrometeorological forecast contains some element of a phenological forecast. Phenological forecasts predict dates of occurrence of main crop development phases, each of which has different climatic requirements. For example, forecasts of the dates of fruit ripening or flower bud burst of fruit trees are important for making operational decisions for marketing and frost protection. However, before such forecasts are embarked on, the reliability and value of these forecasts predictions for each crop need assessing. These forecasts allow farm operation decisions to be made on stock and pasture rotation, supplementary feeding, spraying, harvesting, frost protection, etc. The prediction of ripeness and wilting of pasture species allow decisions to be made on when the main spring growth flush of pastures is over and evaporative demand is large. Decisions then need to be made on stock management, supplementary feeding and irrigation scheduling. Forecasts of the onset of flowering in fruit trees or dates of maturity allow decisions to be made on timing of frost protection and manpower for harvesting and marketing. For pastures the phases to predict include emergence, earing or tasselling/budding, flowering, ripeness and wilting of plants. The predictions of phases in cereal and horticultural crops depend on the plant and are detailed for many species in WMO Tech. Pub. No 593 (1983). The principles of these predictions are based on thermal time (accumulated growing degree-days), photoperiod (daylength) and vernalisation (winter chilling).

- Yield Forecasts

These follow on from phenological forecasts and rely on the development of crop-climate models. In New Zealand, operational yield forecasts have been developed by Maunder (1977a, 1978, 1979) for modelling meat, wool and dairy yields on a national and regional basis. The models are based on empirical-statistical techniques. Other approaches include crop-growth simulation models and crop-weather analysis models. The agrometeorological forecasts should be expanded to predict all crop yields (and hence animal production in the case of pasture) utilising the best and most practically available modelling techniques. Prediction of yields from present and past weather information is extremely important for many on and off farm decisions. However, only those forecasts that are reliable and demonstrate more benefit than a farmer's or farming organisation's educated guess should be made operational.

- Soil Moisture Assessments

Soil moisture is extremely important in determining plant growth. In parts of New Zealand where there is a considerable soil moisture deficit during the production season, information on soil moisture is extremely important for irrigation scheduling. The assessment of available moisture in a 100 cm soil layer at the beginning of the growing season (often spring) is of great assistance to farming. Soil moisture is calculated from past and present climate data using Priestley-Taylor or Penman potential evapotranspiration estimates. These provide the basic assessment and are already made by the Weather Services Group using Thornthwaite potential evapotranspiration estimates. Extrapolation can be achieved by assuming climatological averages. There are improvements possible for calculating soil moisture reserves using models such as the versatile soil moisture budget (Baier et. al., 1972). These could also form part of an agrometeorological bulletin.

Recommendations

It is recommended that some of the suggested forecasts be considered on an operational basis. Of those selected, some need a reasonable amount of research before introduction for development whereas others require very little . To develop this service a reorganisation of forecasting personnel to incorporate an operation shift may be required. This shift could produce forecasts appropriate to the season, whether they are special forecasts, weather for agriculture, agrometeorological forecasts or other non-marine or non-aviation activities. The recommendations are suggested for the medium term rather than as an immediate strategy.

FIGURES

Location Maps of Observations of Climatic Elements Useful in Agriculture

1. Solar radiation stations.
2. Sunshine recorder stations.
3. Climatological stations operating in February 1978 (all record rainfall, maximum and minimum temperature).
4. Stations with soil temperature measurements.
5. Soil thermograph stations.
6. Cup counter anemometer stations.
7. Stations with tank evaporimeters January 1985.

Figure 1. Solar radiation stations.

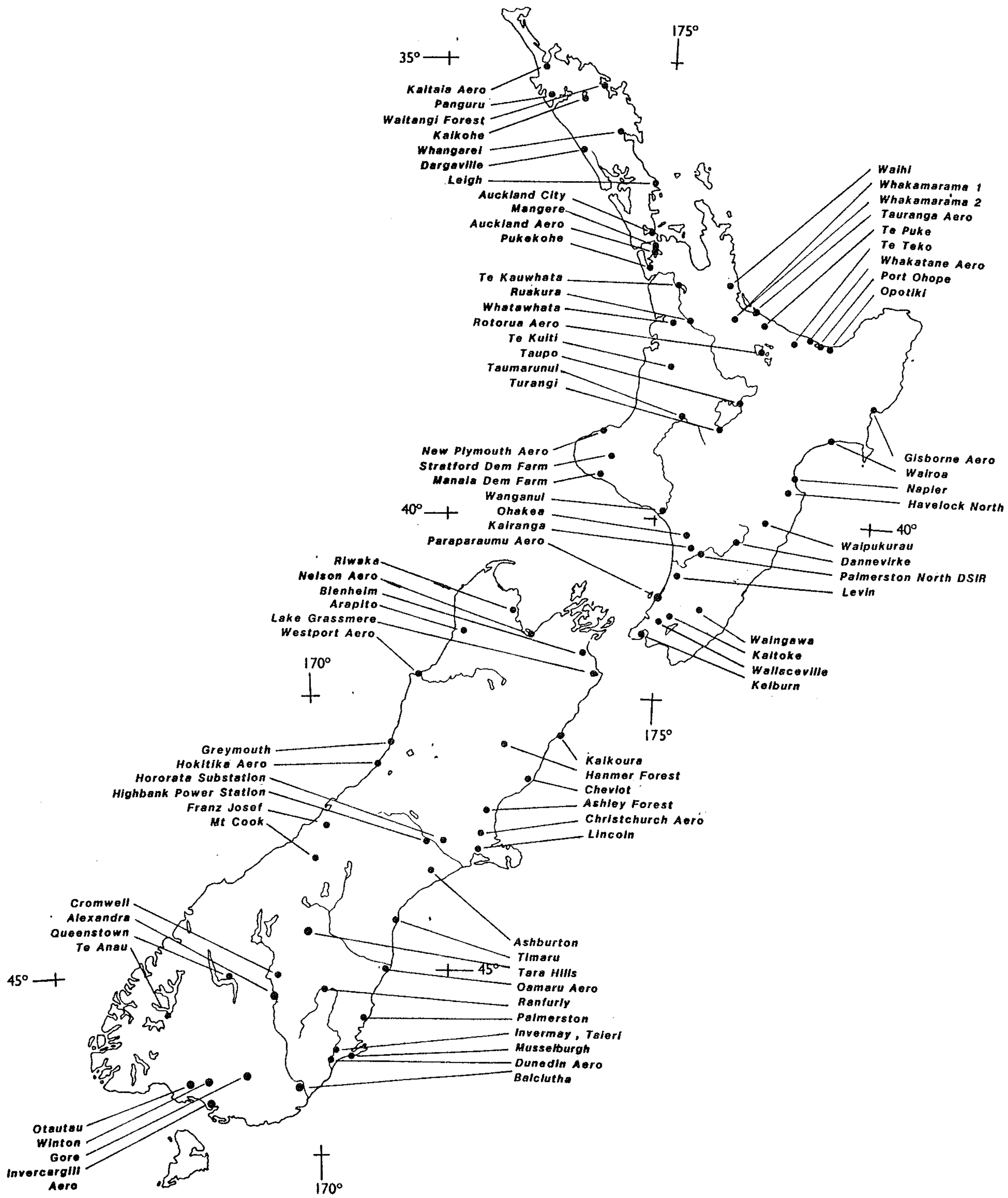


Figure 2. Sunshine recorder stations.

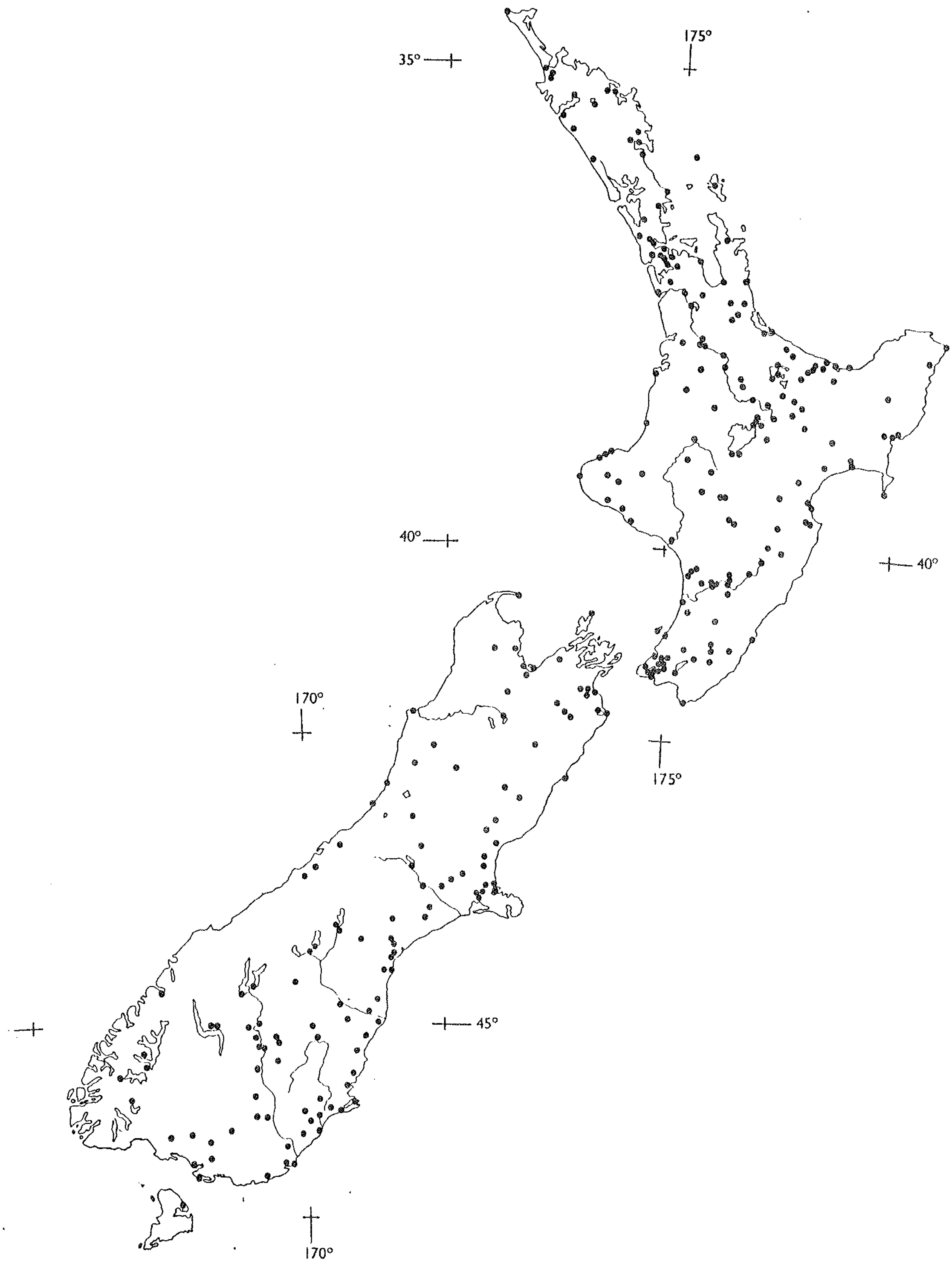
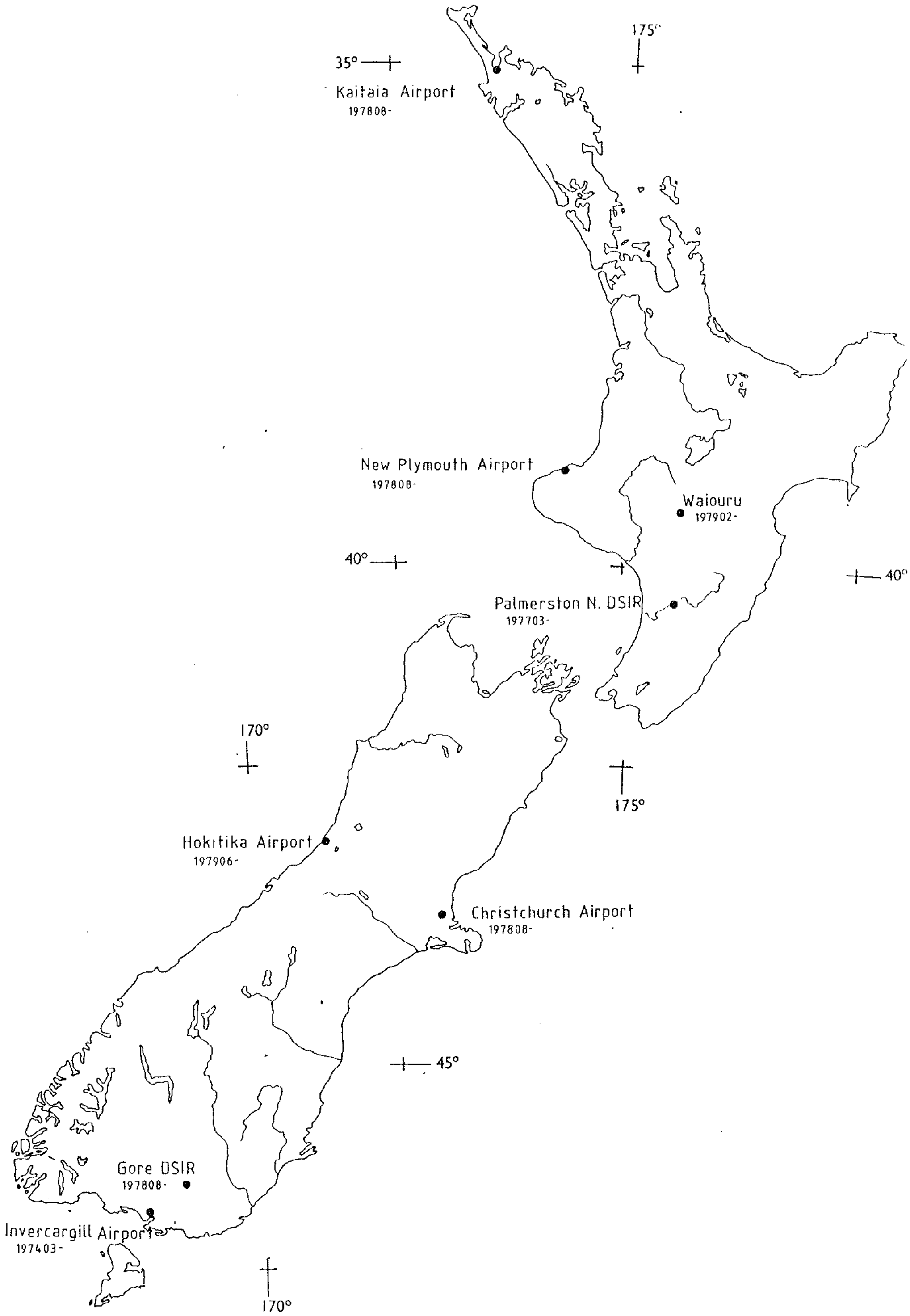


Figure 3. Climatological stations operating in February 1978 (all record rainfall, maximum and minimum temperature).



<u>Figure 4</u>. Stations with soil temperature measurements.

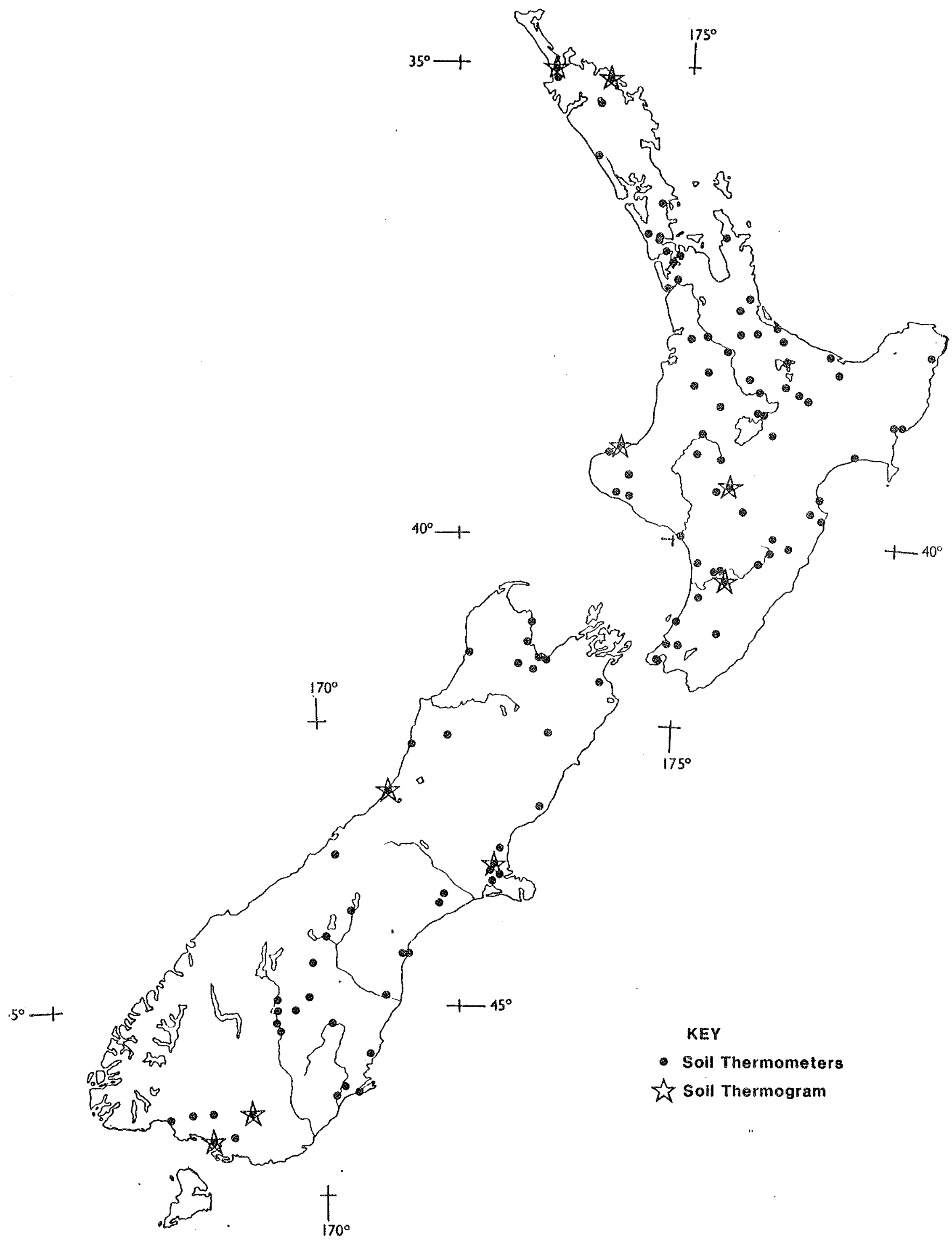


Figure 5. Soil thermograph stations.

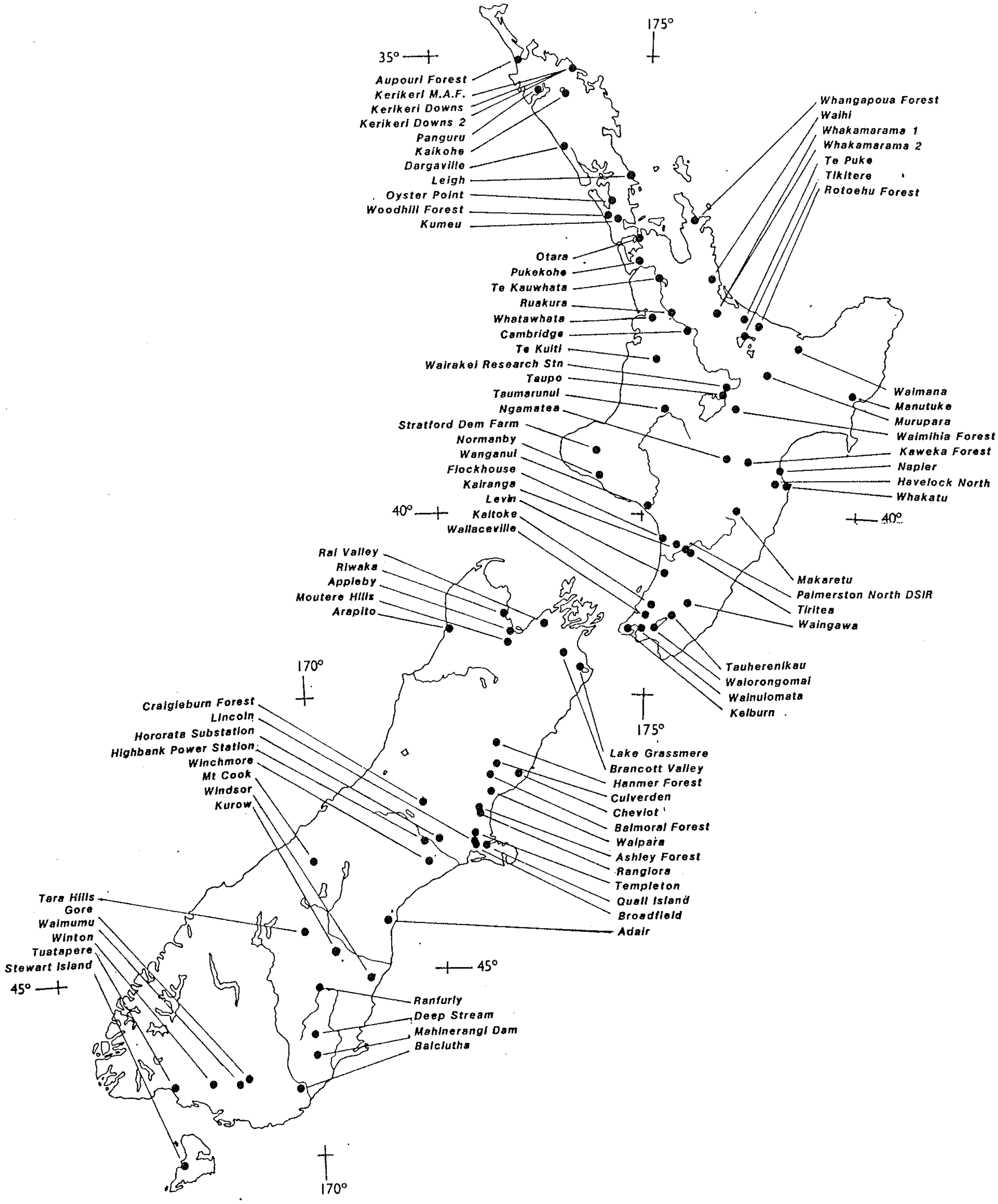
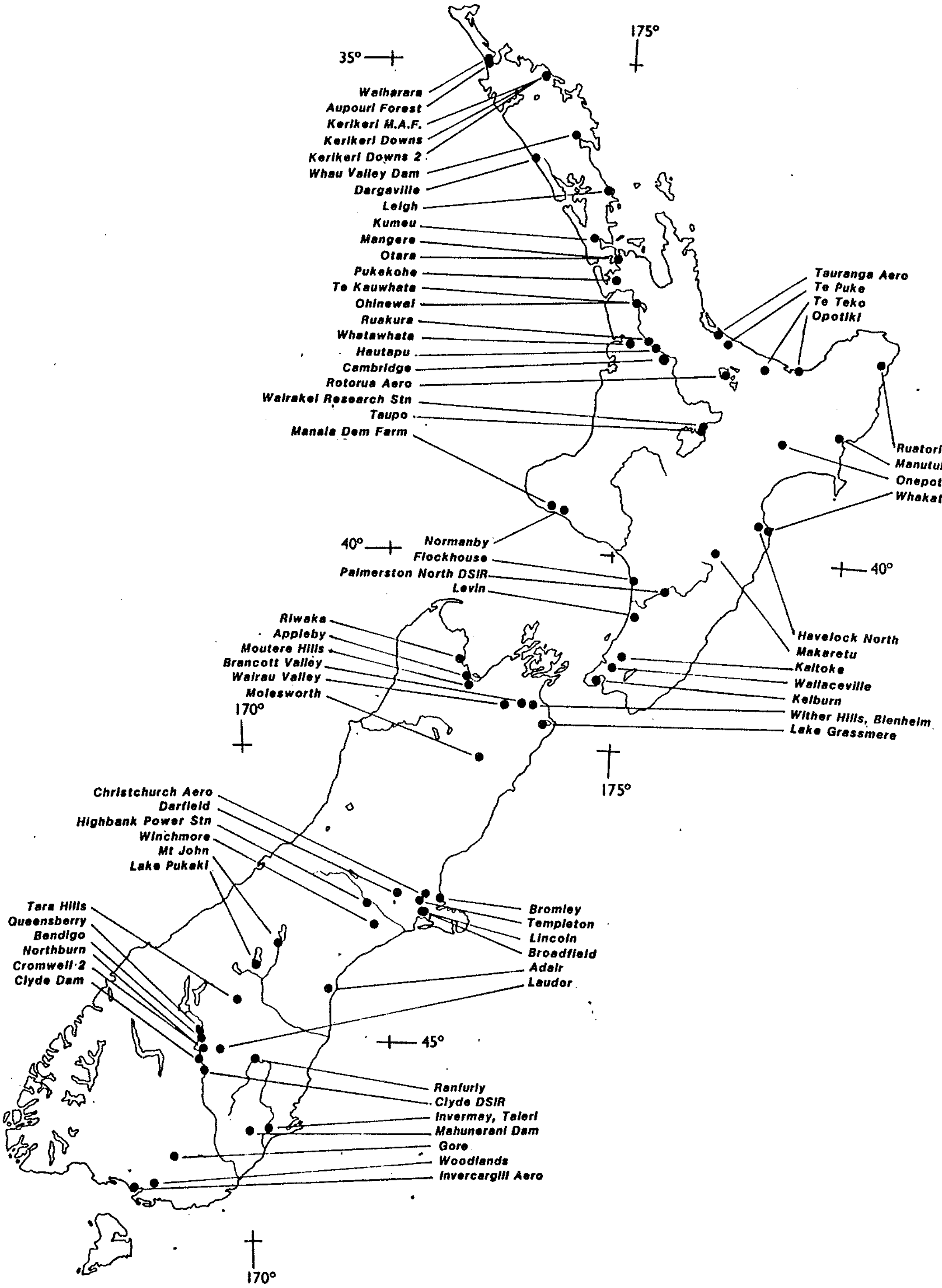


Figure 6. Cup counter anemometer stations.



<u>Figure 7</u>. Stations with tank evaporimeters January 1985.