SOME ASPECTS OF TEMPERATURE VARIABILITY OVER NEW ZEALAND

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ABSTRACT

Some aspects of temperature variability of significance to New Zealand agriculture, but also having general interest, are examined.

Periods of high and low variability in the annual growing degree day accumulations based on data from Auckland and Christchurch over the last 100 years are analysed. By use of a running variance, it is shown that there have been periods of high and low variability in the number of growing degree days per growing year. These periods may be quite sustained. The 1940s and the 1950s, and more particularly the 1890s, were periods of low fluctuation relative to short term mean levels in growing season totals. Especially highly variable periods occurred in the 1880s, the several decades following the turn of the century, and during the 1930s.

Some aspects of spatial variation in temperature related distributions are considered. A representative selection of histograms for long-term records of annual growing degree day accumulations, and date of first frost is discussed.

It is shown that some of the histograms have some quite non-gaussian characteristics. A wide variety of histogram patterns is shown, but some regional patterns are present also. Some implications of these results for agriculture are discussed.

The central theme of this paper is variability. One important variation of temperature is over time. A second important variation of temperature is in space. The study of temperature variation in both these modes may have important agricultural implications. The first part of this paper studies temporal variation in annual accumulations of growing degree days. Such variation has a significant effect on plant productivity The second part of the paper considers spatial variations in histogram form of various temperature distributions. These are important in their consequences for risk and viability studies.

In geological time, New Zealand has undergone many changes in both form and climate. Trenberth (1977) states that during the last glacial period in New Zealand, 20 000 years before the present, the three islands were land linked. No true ice sheet developed. Winters probably contained periods of above-freezing condiditons but temperatures in general were about 6°C below present levels. More recently, evidence from analyses of South Island glaciers shows a distinct glacial period from about 1600 to 1850 AD and this is supported by evidence from a variety of other sources (Burrows and Lucas, 1967; Wardle, 1973).

Long-term records of direct temperature measurements exist for a number of New Zealand locations, and several analyses of these records have been made in recent years (de Lisle, 1968; Maunder, 1973; Salinger, 1979). These appear to show a long-term rise of temperature which began around the turn of the century and accelerated from about 1950. This warming trend is generally opposite to the cooling trend which appears in many northern hemisphere areas since the 1940s, (Hare, 1979), but Hessell (in press) suggests that the apparent New Zealand trend may be largely the result of changes in observational practices, shelter and/or urbanisation since that time.

Humard (1979) emphasises that the rate at which climate change occurs is significant for man's activities. The effect of a long term 1°C change in mean annual temperature is estimated to have a significant effect on irrigation requirements and the choice and distribution of many specialist crops in New Zealand.

However, a study of any unsmoothed temperature series for New Zealand shows that these longer term trends are over-shadowed by the shorter inter-seasonal or inter-annual changes. For the practising farmer, these changes remain the more significant factor in determining his management strategy and the degree of success he enjoys from year to year.

Temporal variability of annual growing degree-day series.

Salinger (1979) has examined climatic change in a New Zealand context, with particular reference to the agricultural implications. He characterises the years 1950 to 1969 as the Green Years for New Zealand agriculture. This period is identified as having been very climatically favourable to New Zealand agriculture.

It is of interest to examine quantitatively the variability of temperature time series over the period 1870 to 1970. The temperature series considered are the annual accumulations of growing degree days above a base of 10°C. These can be taken as a simple representation of the amount of heat available for plant growth over the growing season (Coulter, 1974).

These time series are derived from the long-term records of mean air temperature at Auckland and Christchurch, held by the New Zealand Meteorological Service. They are composite series, with adjustments made for site changes. As well as the difficulties created by gaps in the early records, changes of site and observing practices, it should be recognised that the changing environment will always pose problems of interpretation in the discussion of secular changes in climatological time series. The point of view in the subsequent discussion is to regard the degree day series discussed as the "best" estimate of the degree day accumulations that can be made at this time.

The series are among the longest available and relate to two agriculturally significant regions in New Zealand. They can be taken as broadly representative of growing season conditions in the Auckland-Waikato and Canterbury provinces respectively.

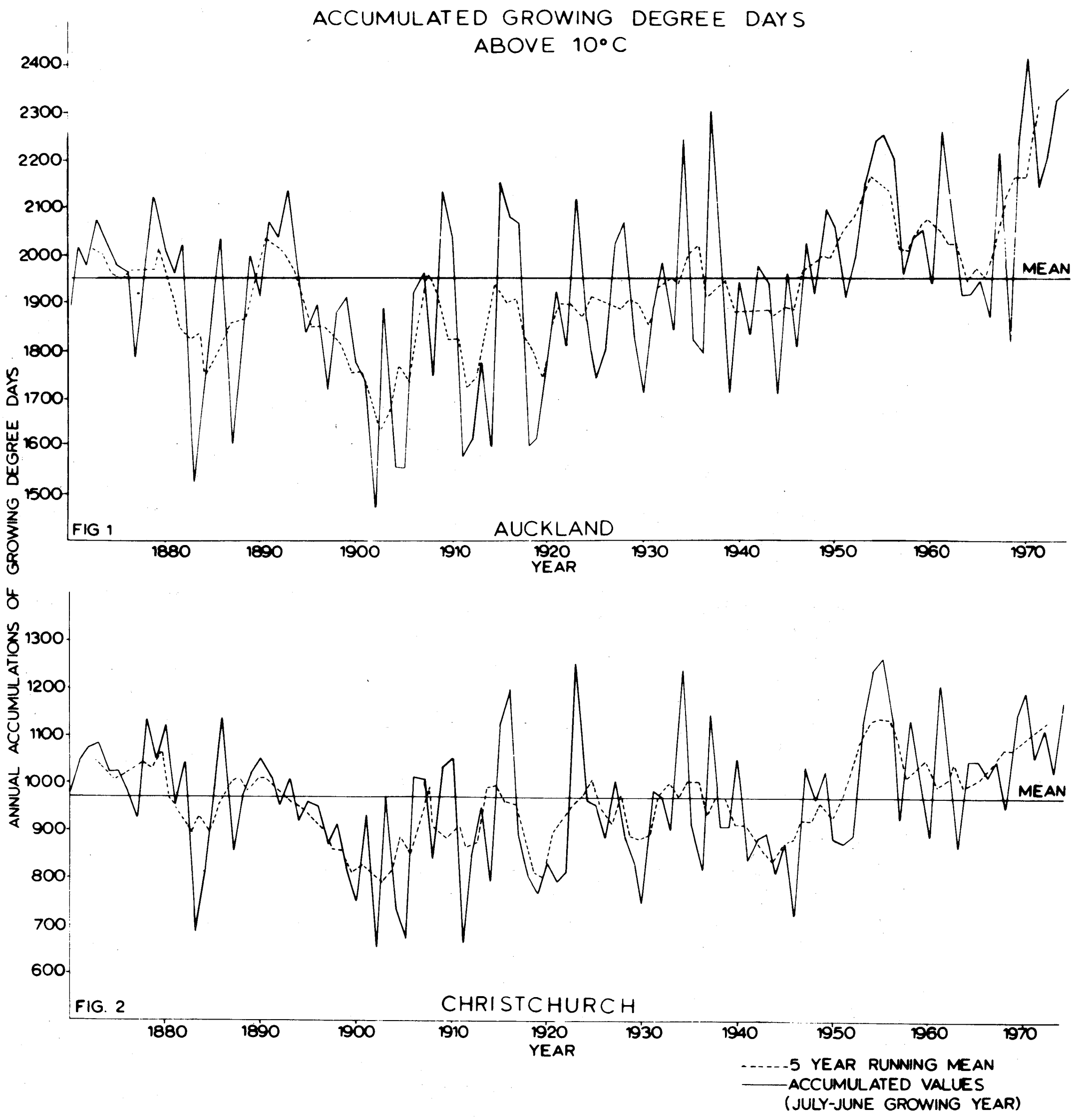
Figures 1 and 2 show the time series of annual growing degree day accumulations for the period 1870 to 1970 from Auckland and Christchurch, together with the five year centred running means (Salinger, 1979).

Outstanding features of both series are the cold conditions with low growing degree day accumulations which occurred during the 1880s and developed again in the 1890s, to become very cold in the early 1900s. Generally below average conditions followed until about 1950, when a large increase in short-term mean levels occurred.

Although these periods of more extreme growing season intensities are highly important for agriculture, a dominant feature of these curves is the large variation from current levels that can occur from year to year, which are in themselves interesting, and are likely to be a considerable influence on agriculture in the short-term.

Since the object of the study was to consider yearly variations from recent general levels of growing degree day accumulations, departures from a

Figures 1 & 2



short-term running mean were taken. A 5 year running mean was chosen to give a reasonably rapid response to changing values of accumulations. It is departures from these 5 year running means that are studied. A five year running variance was then taken on these series of departures. For the study of changing variability this is a natural analogue of the running mean. A 5 year averaging was chosen to give some smoothing but to remain sensitive to more moderate changes. This measure gives a reflection of the mean squared departure from the general level of accumulated growing degree days and thus corresponds to an index of the changeability of the growing season intensity from short term mean levels.

While variations take place on many different scales in the atmosphere, this quantitative measure will emphasise the more sustained periods of large yearly variations from an estimate of 'recent' mean levels.

Figures 3 and 4 show the time series of the Auckland and Christchurch squared residuals, together with the 5 year running means of these squared residuals. A generally higher level of variability at Auckland in absolute terms is apparent.

However, the periods of high variability at each place are generally coincident, as can be seen from the similarity of the 5 year running mean curves in Figures 3 and 4. At Auckland, sustained highly variable periods occurred in the 1880s; from early 1900 to 1919; the thirties; and from the middle sixties to the end of the present analysis. This latter period appeared to develop from early in the decade. At Christchurch a highly variable period in the mid 1880s was followed by further intervals of high variability from the early 1900s to 1916-17; from 1921 to 1925; and a more sustained period in the thirties. A further highly variable period occurred in the late fifties and early sixties.

These variations in growing season intensity are themselves reflections of underlying variation in the general circulation over the New Zealand region. For example, in December 1960 persistent cyclonic activity east of New Zealand with anticyclones over the Tasman Sea brought a predominantly southerly flow onto New Zealand. Heavy rains and low temperatures, especially in eastern districts, resulted. This is partly reflected in the below average degree day accumulations at Christchurch for that year. The following December, persistent anticyclonic activity over and east of New Zealand gave a predominantly northerly flow over the country. Temperatures over the country were much warmer than normal, and there was widespread dryness (Coulter, 1975).

As has been already noted, the use of a 5 year moving average will tend to suppress those short-lived spells of high variability. This is well illustrated in the example just considered.

It is emphasised that the use of annual accumulations itself imposes a strong degree of filtering on the series. Variations which may be very important for agriculture, on the monthly and seasonal scale, occur also but may not be reflected in the annual values.

For an objective analysis of the distribution of the more extreme variability in time, the values of the smoothed variability and the signed residuals, were ranked for both the Auckland and Christchurch records. The 16 and 84 percentile values were calculated, and are presented in Table 1. These percentiles correspond very nearly to 1 standard deviation limits in a normal distribution.

Figure 3

SQUARED DEPARTURES FROM
SHORT TERM MEANS.
AUCKLAND

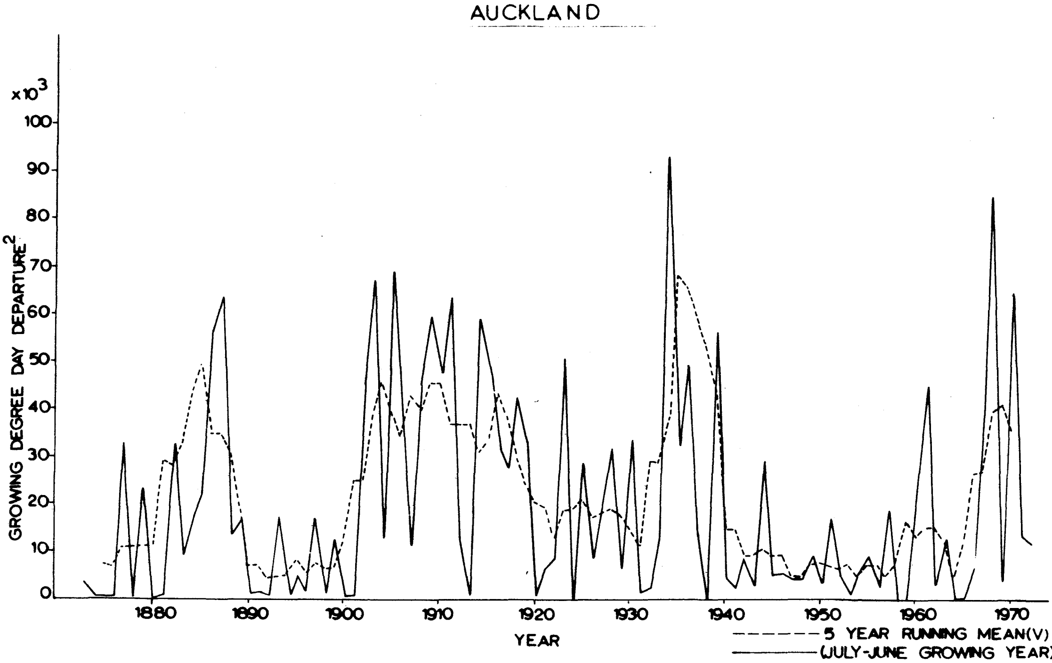


Figure 4

SQUARED DEPARTURES FROM SHORT TERM MEANS. CHRISTCHURCH

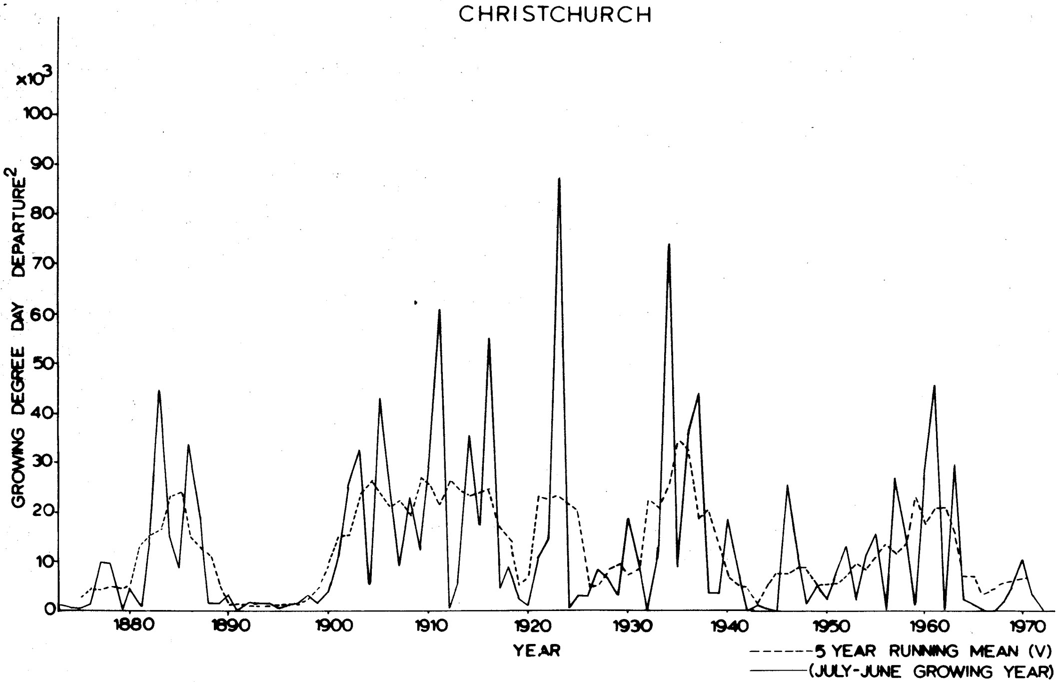


TABLE 1: Thresholds.

	Smoothed variability thresholds (Units: Growing degree days²/year)	
(a)	16 Percentile Value	84 Percentile Value
Auckland	7460	39081
Christchurch	4146	22951

	Signed residual thresholds (Units: Growing degree days)	
(b)	16 Percentile Value	84 Percentile Value
Auckland	−170	159
Christchurch	−119	107

Thus in 1(a), 16 percent of all the values of the quantity V (the five year running mean of the squared departures from the five year running mean of growing degree days) at Auckland are below 7460. From Table 1(b), in 16 percent of the years the difference, annual value -5 year running mean is less than -170.

The 16 and 84 percentile values were used as thresholds, and Table 2 shows in A, the number of occasions per decade the smoothed variability exceeded the 84 percentile value, and B the number of occasions per decade the smoothed variability was exceeded by the 16 percentile value.

A shows the general features already noted. B shows the 1890s to have been an exceptionally 'quiet' period. The period from 1940 was relatively free from large values of variability, and quite rich in periods of rather low variability, especially at Auckland.

C and D both relate to large residuals and there is a good correspondence between both C and D with A. We see here, however, that since 1940 there has been a number of quite extreme residuals, especially at Christchurch, which have been supressed in the smoothed variability approach.

The 1890s then were exceptionally settled relative to mean levels, while the following two decades, and the 1930s appear especially variable. Since 1940, although Christchurch especially has had a fair degree of rather short-lived high variability, the period has been relatively free of high variability of a more sustained nature.

While periods of more extreme variability have been identified, most decades since 1880 have seen the occurrence of some relatively extreme departures of annual growing degree day accumulations at Auckland and Christchurch.

The periods of high variability in the 1880s and following 1900s were associated with below average short-term mean values; however, the 1930s had quite close to average short-term levels.

In risk studies, one is interested in the estimation of frequency of events at a certain level of magnitude, for a given climate parameter. This leads one to consider the form of the distribution, for the estimation of the more extreme events can depend heavily on the distribution form. The spatial variations in these are then of interest.

Spatial variability of histograms of temperature related events

One aspect of spatial variability of temperature is discussed here – the variation in form of histograms of various temperature related events over New Zealand. The distributions of 1) annual accumulations of growing degree days; 2) date of first frost (number of days after 1

TABLE 2: Temporal distribution of extremes.

	1880-	1890-	1900-	1910-	1920-	1930-	1940-	1950-	1960-
Number of occasions per decade when smoothed variability V (A) exceeds and (B) is exceeded by upper 16% value and lower 16% value respectively.									
A.	1880-	1890-	1900-	1910-	1920-	1930-	1940-	1950-	1960-
Auckland	2	0	4	2	0	5	0	0	2
Christchurch	1	0	4	5	2	3	0	0	0
B.									
Auckland	0	7	0	0	0	0	2	5	1
Christchurch	0	9	0	0	1	0	1	0	1
Number of occasions per decade signed departures (C) exceed and (D) are exceeded by upper 16% value and lower 16% value respectively.									
C.	1880-	1890-	1900-	1910-	1920-	1930-	1940-	1950-	1960-
Auckland	2	0	3	4	2	2	0	0	2
Christchurch	2	0	3	3	1	2	2	2	1
D.									
Auckland	2	0	3	4	0	4	1	0	1
Christchurch	3	0	3	2	0	2	1	1	3

January); are considered. An impression of this variation can be gained from Figures 5 and 6, which present a selection of histograms chosen solely to give broad geographic coverage for station records of length exceeding 25years.

The records are of varying length since it was desired to use all the available record, and generally cover the period since the forties. A few, however, are longer. For example, the Christchurch frost date records extend back to early this century.

Figure 5

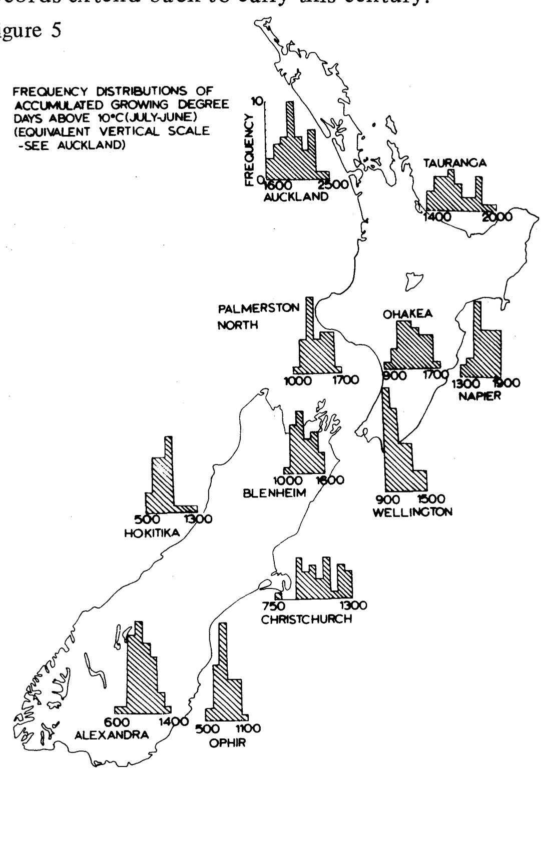
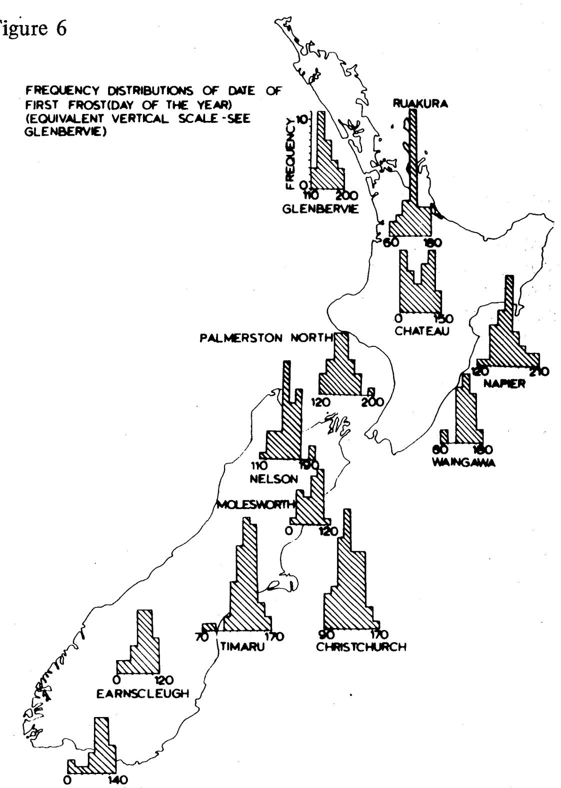


Figure 6



While quite large regional variations in these histograms may occur, similarities within regions also exist. For example, the distributions of accumulated growing degree days at Palmerston North and Ohakea appear broadly similar, as do the pairs Auckland/Tauranga and Alexandra/Ophir.

Although many of these distributions can be fitted quite closely by a normal distribution, there is a strong suggestion of non-normality in some. See, for example, the Christchurch distribution of accumulated growing degree days, Figure 5. There is also a suggestion of more than one mode in some of these distributions, for example, the distribution of dates of first frost at the Chateau. (see Fig. 6).

In overseas work, dates of first and last frost are often assumed to be normally distributed (Waggoner, 1968). This assumption should not be made in New Zealand. For example, the distribution of the Earnscleugh date of first frost (see Fig 6) was taken, and a normal curve was fitted, with the parameters estimated by the sample mean and standard deviation. A test of goodness of fit of this distribution to the actual distribution was made. There was quite good agreement of observed with expected frequencies in all but the lowest cell, and the X^2 value was 3.76 on 3 degrees of freedom, nowhere near even the 10% point of 6.25. However, as might be expected from the skewed appearance of the histogram, the largest contribution to this X^2 value came from the left most cell. Although a normal curve might then appear quite a reasonable fit for such a distribution, it has quite serious consequences for an estimate of say the 10 percentile value of the date of the first frost. On the normal assumption, the 10 percentile value is 8 February, while the estimate from the empirical distribution function is 19 January. Thus, about three weeks separate these two estimates, and the empirical estimate is probably to be preferred for agricultural applications. Use of the 'normal' estimate would appear to seriously under-estimate the frequency of early frost in this case.

Maritime and topographic influences give a broad range of climatic contrasts in New Zealand, and this is reflected in histograms of temperature-related events. There are no *a priori* reasons for expecting the normality of distributions to be general, and in fact for many locations and climate parameters, the distributions may not be. For some applications therefore, the empirical distribution and the percentiles and extremes should be used.

CONCLUSION

There is evidence that in most decades over the period 1870-1970 agriculturally significant variability in the annual degree day accumulations has occurred. There is evidence that the period from about 1940 to the mid sixties has been relatively free of more sustained intervals of high variability, although the Christchurch record shows a short period of quite high variability about 1960. This last decade, 1970-1979, has had periods of high variability.

Although differences exist between regions in the forms of the histograms of temperature related events, there are similarities within regions also. Some of the frequency distributions exhibit quite strongly non-gaussian features, which may be important in applications.

Further work in the Meteorological Service is continuing in the study of spatial and temporal aspects of temperature variability, including frost risk and frost prediction studies, and the smaller scale variations of temperature distributions. Recent work has indicated the presence of quite high persistence on the seasonal scale of earth and air mean temperatures over much of New Zealand from Spring to Autumn. Further investigation of such relationships is continuing. This is part of a longer term objective - the development of the ability to produce useful seasonal forecasts, particularly with regard to agricultural needs.

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