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NATIONAL ECONOCLIMATIC MODELS : PROBLEMS AND APPLICATIONS

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W.J. Maunder

Abstract

Determining the value of the weather to a nation requires an analysis of the manner in which a given weather variation is associated with gains or losses to the economic activities of a nation. Such assessments of nation-wide weather are important, because weather and information about the weather can play an important role in the decision-making processes associated with the management of weather sensitive enterprises. Included in these enterprises are aspects of national economies concerned with nation-wide productivity which are the concern of "high-level" decision makers in the form of national governments. A specific problem is the adjustment of weather data from a wide selection of point sources in order that meaningful weather indices may be used by "high-level" decision-makers.

As a contribution to the development of national econoclimatic models this paper discusses (1) the formulation of weighted precipitation and temperature indices on a weekly basis for the United States, and their application to United States economic indicators in the form of weekly retail trade sales, and (2) the formulation of weighted rainfall, temperature, and water deficit indices on a monthly basis for New Zealand and their application to New Zealand dairy production and New Zealand electric-power consumption.

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These analyses show (1) that many aspects of the United States retail trade are associated with the lateness or otherwise of the important winter and summer seasons, (2) that a close relationship ($r = -0.82$; significant at 0.1% level) exists between total butterfat production in New Zealand in the critical January to April period, and the "dryness" over New Zealand (as estimated from dairy cow weighted water deficit indices), and (3) that 25 per cent ($r = -0.50$; significant at 0.1% level) of the variance of the random oscillation of total New Zealand electricity generation appears to be associated with the departure of the population weighted New Zealand temperature index from the 1931-60 normal.

It is believed that national econoclimatic studies are significant to decision-making at various national levels, the alternative being the omission of meteorological conditions from decision-making, an omission which can lead to incorrect decisions with unfavourable results for the economy.

Introduction

One aspect of climatology is the continuing emphasis on the climate of places, or points, and a general reluctance of climatologists to produce climatic data applicable to areas, particularly areas which are economically important. It has been traditional, for example, for most if not all National Meteorological Services to publish climatic information for places on a routine monthly or, in some cases, weekly basis, and most of the effort of the supporting staff in climatological services is taken up with the routine processing of these point climates. In some cases an attempt is made to map this information, but a deficiency still exists in that the basic climatological data cannot, without modification, be used in association with economic data, which as published is generally related to areas.

It is becoming apparent that much more consideration must be given to the better utilization of the resources of the atmosphere, resources which are capable of being used, misused and modified.* In addition, their "availability" may be forecast. However, until recently the research in applied climatology has been chiefly concerned with the interactions between the atmosphere and physical or biological processes. A much more comprehensive concept of applied meteorology, however, must be used, including the interactions between the atmosphere and man as a decision-maker, for to quote McQuigg (1970b): '... there are situations in which the impact of weather on physical or biological processes is influenced both by the weather events that occur and by the choice of alternatives made by man.' Indeed, as also pointed out by McQuigg

*See, for example, A.H. Perry (1971): "Econoclimate - a new direction for climatology", Area, 3(3), 178-179.

(1970a), man is not only affected by the weather and by information about the weather, but man can and does react to the different kinds of weather through his ability to make decisions.

Weather and information about the weather can therefore play a very important role in the decision-making processes associated with the management of weather-sensitive enterprises. Included in these "weather-sensitive enterprises" are aspects of national economies concerned with productivity, such as the total retail trade, total milk production, total electric power consumption, and even perhaps total unemployment, which are the concern of "high-level" decision-makers in the form of national governments, or boards of directors of national companies. The question whether meaningful relationship can be obtained between weather indices and economic activities over such space scales is valid; however, the continued publication of "weekly and monthly indicators of economic activity" in business journals such as Business Week, and The Economist is an indication that "high-level" decision-makers are interested in these data, and since decisions are undoubtedly made based on these data, it appears not unreasonable to attempt to incorporate into the decision-making process <u>one</u> of the environmental factors which is associated with these national economic indicators - that of the weather. Assuming, therefore, that a relationship does exist between nation-wide economic activities and nation-wide weather, the immediate problem is to establish its magnitude, and in order to do so the problems of establishing such a relationship must be critically examined.

<u>The Value of Weather to an Area</u>

The value of weather to any area requires the identification of activities in that area that are affected directly or indirectly by weather changes, and an analysis of the manner in which a given change results in gains or losses to such activities. This problem has been considered by a number of investigators, including Musgrave (1968) on housing starts, Johnson <u>et al</u> (1969) on electric power consumption, McQuigg and Thompson (1966) on natural gas consumption, Johnson and Haig (1970) on agricultural land prices, Maunder (1968) on agricultural incomes, and Russo (1966) on the construction industry. In most cases, however, these investigations have either been for a restricted area, or they have been related to a period of at least a month. Such studies were not therefore designed to contribute to the more general question of "what is the value of weather in a large area and over a short period of time?".

The increasing interest in the benefits obtainable through a better use of weather information is an associated important aspect of this question. Studies by Maunder (1970a 1971b), Sewell <u>et al</u> (1968), McQuigg (1970b), Taylor (1970, 1971), and Maunder, Johnson, and McQuigg (1971 a,b), for example, show that proper climatological advice can play an important role in the decision-making involved in a weather-sensitive enterprise. Attempts to find associations between economic and climatic data however, present many problems including the incompatibility of the two raw data sets, since economic information is related to areas and climatic data to places. It is usually therefore necessary to transform one or other of the data sets, and from the nature of the information, climatic data generally are the easier to adjust.

As a contribution to the problem of developing national econoclimatic models, this paper now discusses (1) the formulation of weighted precipitation and temperature indices on a weekly basis for the United States, and their application to United States economic indicators in the form of weekly retail trade sales, and (2) the formulation of weighted rainfall, temperature, and water deficit indices on a monthly basis for New Zealand, and their application to New Zealand dairy production and New Zealand electric-power consumption.

The United States Example

In this example the formulation of weighted indices on a weekly basis for the United States is discussed, and their application to national economic indices in the form of United States weekly retail trade statistics. Specifically, a nation-wide weather index is calculated from the mass of point-source weather data available, the point-source data being weighted by taking into account the relative local importance of the retail trade activities. The factors of "large area" (i.e., the United States) and "short time period" (i.e. a week) are chosen deliberately for two reasons: first, that nation-wide economic activities are important to various "high-level" decision-makers, and second, only weather over a short period (such as a week) has any real practical meaning to the "low-level" decision-makers in the form of the many millions of Americans who each day go shopping.

A prime reason for this particular research into weather-economics is to enable nation-wide economic activities to be related to nation-wide weather, a specific aspect of the nation-wide weather being the data published weekly by N.O.A.A. in the Weekly Weather and Crop Bulletin, as well as the five-day nation-wide weather forecasts issued by the National Weather Service.

Various kinds of weekly economic indices are available for the United States; among these are those published by the U.S. Department of Commerce in their Weekly Retail Sales , and these data formed the basis of this investigation. These and many other similar sets of weekly data are only available on a national basis, and although it would be very desirable if weekly regional data were available, the fact that they are not, necessitates the calculation of national weather indices for the same weeks as weekly retail trade data are available.

In order to use these data it is therefore necessary to devise a weekly weather index for the United States as a whole. A problem that arises immediately is that people react to weather rather than to the weather elements of rain, snow, temperature, wind, humidity or sunshine. But, as will be appreciated, the combination of such weather elements into a single weather index is extremely difficult, and although arguments could be advanced for formulating an index following the methods used in agroclimatology (such as de Martonne's or Angstrom's aridity index described by Oury 1965), the problem is still formidable. Moreover, since the only suitable published weather data on a weekly basis for stations in the United States is that in the Weekly Weather and Crop Bulletin, it is justifiable in the first instance to use these data - notably precipitation and temperature - bearing in mind that a combination of the elements sunshine, humidity, temperature, and precipitation duration would probably be more appropriate.

In order to compute a nation-wide rainfall and temperature index, indices were evaluated from "weighted" weekly mean temperature and weekly precipitation departures from normal for 147 places across the United States, most of these places having a 1965 metropolitan population of 300,000 or more. A weighting was then computed for each of the 147 places based on the "buying power index" as published in the Marketing Magazine (10 June 1969) "1969 Survey and Buying Power", as follows:

$$\text{Buying Power Index} = (5I + 3R + 2P)/10$$

where I = % of U.S. Effective Buying Power
R = % of U.S. retail sales
P = % of U.S. population

The "buying power indices" were next used to weight the differences from the normal weekly precipitation and mean temperature for the specific weeks for the 147 stations. The resulting weighted temperature and precipitation departures for the 147 places were then combined into indices for the United States using the following expression:

$$\text{United States Index I} = \frac{\Sigma \, Wi \; Ei}{\Sigma \, Ei}$$

Where: Wi is the rainfall or temperature departure from the average for station i (i = 1 ... 147)

Ei is the "buying power index" for station i (i = 1 ... 147)

An abridged example of the calculation of the weighted temperature and precipitation departures from the normal for the United States for the week ending 12 February 1968 is given in Table 1. The period covered by this study extended over three years; nation-wide precipitation and temperature indices for the United States being computed for each of the 154 weeks from April 1966 to March 1969. The degree of variability of these indices can be judged from the frequency distributions which are given in Table 2.

The method of weighting precipitation and temperature departures on a nation-wide scale, given here, provides one approach to the problem of the incompatibility of nation-wide weather and economic data. It should be noted, however, that most if not all indicators of national economic activity are not designed to be correlated with weather conditions; furthermore, the publication Weekly Retail Sales of the U.S. Department of Commerce which gives estimated weekly retail sales for the United States, is restricted to 13 major store types, and no weekly information is published relating to the weather-sensitive commodities such as ice cream, soft drinks, women's winter and summer clothes, refrigerators, air-conditioners, automobile tyres, beer, iced tea, paint, umbrellas etc.

The weekly retail trade data as published are not adjusted for seasonal or holiday variations, and in view of this the 154 weeks' data were grouped into 11-week overlapping periods. The 11 week periods were centred at the mid-point of the months February to November inclusive in each of the three years. In considering the various 11-week periods certain holiday weeks were excluded, these weeks being replaced by the nearest non-holiday week outside the 11-week period. In addition, because of Christmas, the analyses were not extended into December.

The associations between retail trade sales and the weighted precipitation and temperature indices for the United States (Table 3) were assessed using the following regression equation:

$$x_1 = a_0 + a_1 x_2 + a_2 x_2^2 + a_3 x_3 + a_4 x_4$$

where x_1 = retail sales for the specific kind of retail business for specific weeks

x_2 = time factor (week 1, 2 ... 11)

x_3 = weighted precipitation departure for the United States for specific weeks

x_4 = weighted temperature departure for the United States for specific weeks

a_j = constants

The regression equation is of a form which has been used extensively in agroclimatology (see, for example: Oury 1965, Doll 1967, Thompson 1962), the equation in this case allowing an assessment of the relationship between variations in retail trade sales from a quadratic time trend (over the specific 11 week periods), and the variations in the nation-wide precipitation and temperature indices.

The inter-relationships between first, the weighted precipitation departure (x_3) and the retail sales (x_1), and second the weighted temperature departure (x_4) and the retail sales (x_1), were then examined using the relevant partial correlations. Analyses were made for all the 11 week periods (except December) in the three years for all 13 aspects of the retail trade. [1]

Weather - Retail Trade Associations

An analysis of the partial correlations significant at the 5% level (see Maunder, 1972a, for a more detailed analysis) shows a probable greater importance of temperature to retail trade sales than precipitation, a result which agrees in general with some other studies. Perhaps the most striking feature of the analysis, however, is the apparent close association of late winter to early summer conditions with retail sales variations, in contrast to the absence of many significant associations with weather variations in August and September. [2]

The generalised relationships between the weighted precipitation and temperature indices and weekly retail trade are summarised in Table 4. It is emphasised, however, that the associations obtained are from only three years of overlapping 11 week periods, and that the results are purposely designed to apply to the United States as a whole. Moreover, the published data on weekly retail trade refer to kinds of business and not to the more weather-sensitive commodities sold. The associations obtained must therefore be treated with caution but they do indicate the following nation-wide features:

(1) that drier conditions than normal (for the specific weeks concerned) appear to be generally associated with above average retail sales (for the specific week concerned) in late winter, and during the early fall,

(2) that wetter conditions than normal appear to be generally associated with above average retail sales in late spring and early summer,,

(3) that colder conditions than normal appear to be generally associated with above average retail sales in the fall, and

(4) that warmer conditions than normal appear to be generally associated with above average retail sales in spring and early summer.

As would be expected with weather and economic data "averaged" over a large and inhomogeneous area such as the United States, the econoclimatic associations revealed by the partial correlations vary in their significance, and for some retail-trade groups and during some of the 11 week periods, the indicated relationships have limited practical value. However, it is believed that the partial correlations do give a valuable insight into the relationship between weekly weather conditions on a national scale and published weekly retail sales on a national scale, particularly in regard to the seasonal sensitivity of various kinds of retail sales to precipitation and temperature variations from the normal. The analysis in fact gives emphasis to the generally held view that many aspects of the variations in the retail trade in the United States are associated with the lateness or otherwise of the winter and summer seasons.

The New Zealand Example

The basic economic unit for statistical purposes in New Zealand is the county, and although some counties extend over more than one "geographical region", the counties in New Zealand can be used as the basis for a regional breakdown of economic activities. Indeed, in many instances, the county is the only data source which can be used for a regional division of New Zealand.

In 1969 there were 110 counties in New Zealand, and it is appropriate to use "economic" data from these counties - and the climatic data applicable to one or more climatological stations in each county - as the basis for the formulation of weighted weather indices. It should be noted that the counties used are the "geographical counties"; that is, they are the "administrative counties" plus the "population" within any cities, boroughs, or independent town districts which are included within the boundaries of the geographical county as defined by the Department of Statistics.[5]

As of July 1971, there were 260 climatological stations in New Zealand, and from these stations one representative climatological station was selected for each geographical county. In many counties there was only one climatological station available, and such stations were automatically used in the analysis. In a few cases such as Whangaroa County in Northland, and Oxford County in Canterbury, however, there were no climatological stations within the county boundaries, and in these cases the county concerned was combined with an adjacent county in which a climatological station was located. There were also cases where more than one climatological station was available such as Waitaki County with Tara Hills and Oamaru, or Hutt County with Wallaceville, Kelburn, Wellington Airport and Paraparaumu. In these counties, consideration was given to significance of the county from a "population" or "area" viewpoint and in 10 counties the weightings of two climatological stations were used. In three other counties or county groups (Hutt, Golden Bay/Waimea, Paparua/Waimairi/Heathcote/Halswell, Mount Herbert), three climatological stations were used, while the Waitemata geographical county with a 1966 population of 449,000 people was considered in association with four climatological stations (Whenuapai, Albert Park/Auckland, Oratia, Owairaka). A complete list of the counties and the climatological stations used in the analyses is given in the Appendix.

The calculation of the weightings of the climatic data applicable to the climatological stations used in the analysis is based on the contribution of the geographical county to the New Zealand total "population" or "area" (see Maunder, (1972b), for a more detailed analysis). For example, data showing the contributions of the Hutt, Waikato, Waimate, and Southland Counties are given in Table 5, and this shows that there are relatively large differences in the economic base of various areas of New Zealand. It follows therefore that, as in the case of the United States example, the assessment of the weather effects on economic activities in New Zealand should take into account the relative significance of "activities" in various areas.

In the following analysis, three climatological elements (rainfall, mean temperature, days with water deficit) are used to obtain three weighted climatic indices, the weightings used being (1) land area, (2) human population, (3) sheep population (4 dairy cow population, (5) beef cattle population, and (6) crop area. Accordingly, for each month assessed, six weighted indices were computed for each of rainfall, mean temperature, and days with water deficit. A specific example is now given for March 1969.

In the first case rainfalls at 109 climatological stations (the stations are given in the Appendix) were expressed as a percentage of the 1921-50 normal rainfall for the specific stations. For example, in March 1969, Kaitaia Aerodrome had 5 percent of the normal rainfall, Rukuhia 47 percent, Ruatoria 2 percent, Milford Sound 172 percent, and Christchurch 14 percent. These percentages were then weighted by multiplying them by the county contribution of the New Zealand total population or area. In the case of Waimate County, for example, the Waimate climatological station rainfall percentage of 40 percent was multiplied by 0.3 for human population, 1.4 for land area, 1.9 for sheep population, 0.1 for dairy cow population, 0.7 for beef cattle population, and 1.4 for crop area. A similar procedure was followed for the other geographical counties, except in those cases where two or more climatological stations were used. In these latter cases, the county population or area was subdivided so that each climatological station was associated with a proportion of the total county weight.

In the second case, the number of days per month with a "water deficit" (based on a Thornthwaite assessment of "water deficit" and assuming a soil moisture capacity of 3 in. (75 mm)) were weighted using the same method. Thirdly, a weighted temperature departure from the 1931-60 temperature normal was calculated based on the weightings of 78 of the 109 climatological stations listed in the Appendix.

The weighted county climatic indices for each month were next combined into climatic indices using the following formula:

$$\text{Climatic Index I} = \frac{\Sigma\, C_i\, E_i}{\Sigma\, E_i}$$

where: C_i is either the rainfall for station i expressed as a percentage of 1921-50 normal, the mean temperature departure for station i from the 1931-60 normal, or the actual number of days with water deficit (per month) for station i; E_i is the percentage of the New Zealand economic parameter in county i; and I is a climatic index which ranges from 0 to over 200 in the case of rainfall, $\pm$ x.x ^{o}F in the case of temperature departure, and 0 to 31 days in the case of days per month with water deficit. The indices may therefore be considered indices of "warmth", "coolness", "wetness" or "dryness".

An example of the computation of a regional rainfall index for March 1969 is given in Table 6 for the South Canterbury/North Otago area, and it shows that the degree of dryness was greatest in the cropped areas and least if the total land area was considered. It should be noted, however, that as with all monthly rainfall figures, the monthly rainfall indices do not necessarily imply that the rainfall (or the dryness) was evenly distributed during the month. It is probable in fact that most of the rainfall in a month with a weighted rainfall index of 200 could have occurred in the latter half of the month. One method of overcoming this deficiency is the use of daily climatic information, and an initial approach is given here by using the "number of days per month with water deficit". For example, in the case of the South Canterbury/North Otago region shown in Table 6, the weighted "days with water deficits" vary from 24 in the case of human population and dairy cows, to 20 in the case of land area. Thus a rainfall index weighted according to land area of 70 may be compared with a weighted "days with water deficit" of 20 days, whereas a rainfall index of 53 (weighted by crop area) may be compared with a "water deficit" index of 23 days.

Similar computations to those shown in Table 6 for the South Canterbury/North Otago region were made for 20 other regions in New Zealand, together with the North and South Islands, and for New Zealand as a whole (the 21 regions are shown in Fig. 1). Table 7 shows the weighted rainfall and water deficit indices for selected New Zealand regions for March 1969 and this indicates very clearly two important factors - first, the variation from one region to another, and second, and most important, the variations which occur if different economic parameters are considered. In particular, they indicate the relatively severe dry period which was prevalent at that time, the "dryness" index depending on the economic parameters considered.

Using the methods already discussed, monthly climatic indices for rainfall, mean temperature, and days of water deficit were computed for each month over the last several years. Some of these indices are given in Tables 8, 9, 10 and relate to New Zealand as a whole. Similar indices for 21 regions in New Zealand, together with indices for the North Island and the South Island were also computed and are available on request. A selection of these indices for New Zealand for each month from January 1969 to April 1970 for three economically important weightings is also shown in Table 11. It is believed that such indices are of considerable value in assessing the overall "wetness" of "dryness", or "warmth", or "coolness" of New Zealand in any month. For example, if the human population parameter is considered to reflect urbanised New Zealand then an analysis of the two precipitation indices weighted according to the human population should indicate the degree of "wetness" or "dryness" of urbanised areas in recent years, whereas the temperature index should indicate the degree of "warmth" or "coolness".

The primary purpose in developing the weighted climatic indices is to provide a means by which a vast amount of climatological data can be conveniently expressed as an index which is both representative of the climatic data and also meaningful to studies relating climatic events to economic activities. The application of such indices to economic activities, however, is not easy, and McQuigg (1967) in commenting on the problem states that anyone trying to write a set of equations, or set of logical restraints, suitable for inclusion in a model to be used in a study of the impact of weather events on human activities, will find very quickly that we know very little in quantified terms that can be used in this way. McQuigg was referring specifically to the situation in the United States, but the same or a worse situation exists in New Zealand. Indeed the basic handicap to applying weather information to nation-wide economic activities in New Zealand is the almost complete lack of monthly (and weekly) economic indicators. Two notable exceptions are those associated with the consumption of electric power and the processing of butterfat in dairy factories, and national econoclimatic analyses of these two aspects of the New Zealand economy are briefly discussed.

Applications of New Zealand Model

The butterfat processed by dairy factories in New Zealand for the months January, February, March and April in the years 1966 to 1970 is shown in Table 12 together with two climatic indices, each weighted according to the population of dairy cows in milk. The "expected" production in each of the months was assessed graphically and Table 12 lists the "differences from the expected" production. It is believed that these differences reflect a true variation in the butterfat processed by dairy factories, and as shown this variation appears to be closely associated with the two climatic indices given. [4] As would be expected, there is some lag between the actual weather experienced and production, but as a first approximation the number of days with a water deficit in the month of production and in the two preceding months can be used as a "wetness" or "dryness" index for correlation with the "difference from the expected" production. Such an analysis (Figure 2) indicates a relatively close relationship ($r = -0.82$; significant at 0.1% level) between butterfat production in New Zealand as a whole, and a "dryness" index for New Zealand as a whole.

The econoclimatic relationships between temperatures and hourly electric power production in New Zealand have been initially investigated by the author (Maunder, 1971a), and preliminary results of an assessment of the relationship between the weighted temperature departure for New Zealand (weighted according to the distribution of the human population), and the random oscillation of total electricity generation in New Zealand (as determined by the Department of Statistics, after allowance for seasonality, trend, and "work" days) shows a similar close relationship. The analysis (Figure 3) covered the 120 months in the 1961-70 decade, and indicated that 25% ($r = -0.50$; significant at the 0.1% level) of the variance in the random oscillation of New Zealand electricity generation was associated with the departure of the weighted New Zealand temperature index from the 1931-60 normal. Such an analysis provides therefore a valuable insight into the temperature sensitivity of an important section of the New Zealand economy.

Conclusion

An important factor in any national econoclimatic study is that most economically associated information is related to areas, whereas most published climatic data applies to places. It is believed that the method of adjusting weather and climatic data to fit various kinds of nation-wide economic data, as described in this paper, offers a solution to the data problem confronting studies in weather economics.

As has been emphasised, it would be very desirable if weekly regional data for the economically important activities of various nations were available for use in econoclimatic studies, but since in most if not all nations this is not the case, it is necessary to devise methods to incorporate nation-wide economic data into econoclimatic studies. It is believed that the results of such studies are significant to decision-making at various national levels, the alternative being the omission of meteorological conditions from decision-making, an omission which can lead to incorrect decisions with unfavourable results for the economy.

The methods of adjusting weather data used in this paper are only some of a large number of possible adjustments. Additional "weightings" could also be evaluated and these could provide useful nation-wide weather indices for such additional economic activities as forest protection, crop production, road construction, building construction, communications, electric power generation, transportation, and tourism.

If climatic information is to be used effectively in the decision-making process, it is essential that it be in a form that is appropriate to the user. It is believed that the models described here for the United States and New Zealand provide a useful method of translating weather information into more meaningful indices which may be used with profit by the "high-level" decision-makers of the more weather-sensitive aspects of national economies.

Notes

1. Because of the small size of the sample, however, the precipitation/retail trade and temperature/retail trade correlation coefficients for each corresponding 11 week period in the three years were combined, by converting the r values to Fisher's z' values, finding a weighted mean of the z' values, and then converting back to a new r value (see Brooks and Carruthers, 1953, p.222).

2. The month of October, however, is again relatively weather-sensitive as far as retail sales are concerned and it is likely that November is also particularly weather-sensitive. Because of difficulties in incorporating the Christmas sales in the 11 week period centred on November, however, the analysis reported here did not extend beyond the 11 week period centred on October.

3. For example, the Hutt geographical county at the 1966 census, had a population of 296,156, this figure including 41,284 in the Hutt administrative county, 131,555 in Wellington City, 22,190 in Porirua City, 19,084 in Upper Hutt City, etc. The advantage of using the geographical county is that the total New Zealand "population" (of people, animals, or land etc.) can be subdivided into county areas.

4. It should be so noted that more refined analyses on the relationship between climatic factors and butterfat production have been made (see for example: Curry (1958), McMeekan (1960), Maunder (1968)), but in these studies the productivity and climatic factors were primarily concerned with small areas, whereas the purpose of developing "wetness" indices as described in this paper is to provide a means of associating production with climatic factors on a regional and national scale.

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Appendix. List of geographical counties and associated climatological station(s).

	Region	Geographical county(s)	Climatological station(s)
1.	Northland	Mangonui/Whangaroa	Kaitaia Air.
		Hokianga	Waipoua Forest
		Bay of Islands	Kerikeri
		Hobson	Dargaville
		Whangarei	Glenbervie Forest
2.	Auckland	Rodney	Takatu, Matakana
		Waitemata	Whenuapai/Albert Park/Oratia/ Owairaka
		Great Barrier Is.	Port Fitzroy
		Franklin	Otara/Maioro Forest
3.	Coromandel	Coromandel	Whangapoua Forest
		Thames	Thames
		Ohinemuri	Waihi
4.	Waikato	Piako	Te Aroha
		Hauraki Plains	Ngatea
		Waikato	Ruakura
		Raglan	Whatawhata
		Waipa	Rukuhia
		Matamata	Arapuni
		Otorohanga	Waikeria
5.	Bay of Plenty/ Taupo	Tauranga	Tauranga Air.
		Whakatane	Whakatane/Minginui Forest
		Rotorua	Whakarewarewa
		Taupo	Taupo
		Opotiki	Opotiki
6.	Gisborne	Waiapu	Ruatoria
		Waikohu	Mangatu Forest
		Cook	Gisborne Air.
7.	Hawke's Bay	Hawke's Bay	Napier/Havelock North
		Waipawa	Gwavas Forest
		Wairoa	Frasertown, Wairoa
		Woodville	Waipuna, Woodville
		Waipukurau	Waipukurau
		Patangata/Dannevirke	Dannevirke
8.	Waitomo/King Country	Waitomo	Te Kuiti
		Taumarunui	Taumarunui/Chateau Tongariro
		Waimarino	Ohakune
9.	Taranaki	Clifton	Mohakatino Station
		Taranaki	New Plymouth Air.
		Inglewood	Te Wera Forest
		Stratford	Stratford
		Egmont/Eltham	Stratford Mountain House
		Waimate West/Hawera	Manaia
		Patea	Patea Freezing Co.

Appendix (contd)

Region	Geographical county(s)	Climatological station(s)
10. Wanganui	Rangitikei	Hiwi, Taihape/Ohakea
	Waitotara/Wanganui	Wanganui
11. Manawatu	Kiwitea/Pohangina/Oroua	Palmerston North Air.
	Manawatu/Kairanga	Palmerston North D.S.I.R.
	Horowhenua	Levin
12. Wairarapa	Pahiatua/Akitio	Mangamutu, Pahiatua
	Eketahuna	Mangamahoe
	Masterton	Waingawa, Masterton
	Wairarapa South	Martinborough/Riverside
	Featherston	Waiorongomai
13. Wellington	Hutt	Kelburn, Wellington/Paraparaumu Air./Wallaceville
14. Nelson	Golden Bay/Waimea	Riwaka/Nelson Air./Golden Downs
15. West Coast	Buller	Westport Air.
	Westland	Hokitika Air./Haast
	Inangahua	Reefton
	Grey	Greymouth
	Lake (part only)	Milford Sound
	Fiord	West Arm, Lake Manapouri
16. Marlborough	Marlborough	Blenheim Air.
	Awatere	Molesworth
	Kaikoura	Kaikoura
17. North Canterbury	Amuri/Cheviot	Hanmer Forest
	Waipara	Balmoral Forest
	Kowai/Ashley/Oxford	Ashley Forest
	Rangiora	Loburn
	Eyre	Eyrewell Forest
	Tawera/Malvern	Darfield
	(Paparua/Waimairi/ (Heathcote/Halswell/ (Mount Herbert	(Christchurch Air./Christchurch (Gardens/Bromley
	Akaroa/Wairewa	Onawe, Akaroa
	Ellesmere	Lincoln
18. South Canterbury/North Otago	Ashburton	Ashburton/Lake Coleridge
	MacKenzie	Lake Tekapo
	Geraldine	Timaru Air.
	Levels	Timaru
	Waimate	Waimate Air.
	Waitaki	Oamaru/Tara Hills

Appendix (contd)

Region	Geographical county(s)	Climatological station(s)
19. Coastal Otago	Waihemo	Mount Royal, Palmerston
	Waikouaiti	Cherry Farm, Waikouaiti
	Peninsula/Taieri	Musselburgh, Dunedin/ Dunedin Air.
	Bruce	Milton
	Clutha	Balclutha
20. Central Otago	Maniototo	Naseby Forest
	Vincent	Alexandra
	Lake (part only)	Queenstown
	Tuapeka	Roxburgh Power Station
21. Southland	Wallace	Otautau
	Southland/Stewart Island	Gore/Invercargill Air.

Table 1. Abridged example of the calculation of temperature* and precipitation** departures from the normal for the United States for the week ending 12 February, 1968, weighted according to the "buying power index" of 147 localities

No.	Station	"Buying power index" (U.S.= 100)	Departure from normal		Weighted differences	
			Temp. (°F)	Precip. (in.)	Temp. (°F)	Precip. (in.)
1	Birmingham, Alabama	0.32	-9	-1.3	-2.8	-0.42
6	Tucson, Arizona	0.15	+9	+0.5	+1.4	+0.08
15	Denver, Colorado	0.62	+4	-0.2	+2.4	-0.12
19	Washington, D.C.	1.67	-2	-0.5	-3.3	-0.84
22	Miami, Florida	0.63	-8	-0.2	-5.0	-0.13
32	Chicago, Illinois	4.22	-2	-0.3	-8.4	-1.23
50	New Orleans, Louisiana	0.50	-11	-1.0	-5.5	-0.50
65	Kansas City, Missouri	0.76	-3	-0.3	-2.3	+0.23
72	Las Vegas, Nevada	0.14	+3	+0.1	+0.4	+0.01
80	New York, New York	9.27	-4	-0.8	-37.1	-7.42
122	Dallas, Texas	0.79	-1	-0.6	-0.8	-0.47
132	Salt Lake City, Utah	0.26	-4	-0.3	+1.0	-0.08
140	Yakima, Washington	0.07	+1	-0.2	+0.1	-0.01
145	Madison, Wisconsin	0.14	-1	-0.2	-0.1	-0.03
147	Cheyenne, Wyoming	0.03	+7	-0.1	+0.2	-0.00
Total (147 stations):		63.12	-	-	-152.8	-35.35

* Total weighted temperature departure = -152.8
Average departure = -152.8/63.12 = -2.4°F (-1.3°C)

** Total weighted precipitation departure = -35.35
Average departure = -35.35/63.12 = -0.56 in. (-14.2 mm)

Table 2. Frequency of the departure from the normal of weighted weekly temperature and precipitation indices for the United States : April 1966 - March 1969.

Temperature (^{o}F)			Precipitation (in.)		
Departure from normal	Number	%	Departure from normal	Number	%
+8 or more	4	3	+0.8 or more	1	1
+5 or 6 or 7	7	4	+0.5 to 0.7	17	11
+3 or 4	15	9	+0.3 or 0.4	15	9
+2	16	10	+0.2	14	9
+1	18	12	+0.1	18	12
0	17	11	0	15	9
-1	19	13	-0.1	16	10
-2	17	11	-0.2	18	12
-3 or 4	23	15	-0.3 or 0.4	28	19
-5 or 6 or 7	13	9	-0.5 to 0.7	12	8
-8 or more	5	3	-0.8 or more	0	0
Total	154	100		154	100

Table 3. Selected weekly retail trade sales* in the United States for the period January to March 1968 and associated precipitation and temperature indices weighted according to the "buying power index" of 147 localities

Period	Kind of retail business (millions of dollars)					Weighted indices **	
Week ending Saturday	Total retail trade	Apparel group	Furniture and appliances	Lumber building Hardware	Drug stores	Precip. (in.)	Temp. (°F)
Jan. 13	5344	284	250	227	205	+0.10	-8.5
Jan. 20	5562	296	281	255	215	-0.32	+1.9
Jan. 27	5581	273	276	264	208	-0.28	+1.8
Feb. 3	5706	277	295	275	203	+0.28	+6.4
Feb. 10	5720	292	287	286	210	-0.56	-2.4
Feb. 17	5772	264	278	297	227	-0.43	-5.8
Feb. 24	5778	284	302	287	200	-0.48	-6.3
Mar. 2	6049	275	295	315	207	-0.25	-2.8
Mar. 9	5957	306	291	316	214	-0.16	-1.7
Mar. 16	5967	306	271	330	199	+0.74	-1.6
Mar. 23	6121	327	279	342	206	+0.17	+0.8
Mar. 30	6548	376	304	376	196	-0.51	+7.5

* Weekly sales estimates are based on data from 2,500 firms, covering approximately 48,000 retail stores in the United States.

Source of data: Weekly Retail Sales Report - U.S. Department of Commerce/Bureau of the Census. Note: Data are not adjusted for seasonal or holiday variations.

** Weighted weather indices are for week ending midnight on the Sunday of the week indicated. The indices shown are departures from the normal for the specific week.

Table 4. Generalised relationships* between precipitation and temperature differences from the average and above average retail sales in the United States

Kind of business	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Food group	-	-	-	-	warmer	-	-	-	-
Grocery stores	-	-	-	wetter	warmer	-	-	-	colder
Chain grocery stores	-	-	-	wetter	warmer	-	-	-	colder
Eating and drinking places	-	-	-	-	warmer	-	-	-	-
General merchandise, apparel, furniture	drier	warmer	-	(wetter (warmer	wetter	-	-	-	-
General merchandise	-	warmer	wetter	(wetter (warmer	(wetter (warmer	-	-	-	-
Department stores	-	(wetter (warmer	wetter	(wetter (warmer	(wetter (warmer	-	-	-	-
Apparel group	(drier (warmer	warmer	warmer	wetter	wetter	-	-	-	-
Furniture and appliance group		-	warmer	warmer	warmer	warmer	-	-	(drier (warmer
Lumber, building, hardware, farm equipment	wetter	(wetter (warmer	-	-	-	-	-	-	drier
Automotive group	-	(wetter (warmer	warmer	-	-	wetter	-	-	-
Gasolene service stations	drier	-	-	-	-	colder	-	-	-
Drug and proprietary stores	drier	drier	-	-	(wetter (warmer	-	-	-	-

* The relationships shown are those in which the relevant partial correlations are significant at the 20% level.

Table 5. Relative Significance of four geographical counties in New Zealand*. Data indicates percentage of New Zealand total.

Economic Parameter	Geographical County				New Zealand Total
	Waikato	Hutt	Waimate	Southland	
Human population	1.0	11.1	0.3	3.3	2,677,000
Land area	0.6	0.6	1.4	3.6	103,000 sq.mls
Sheep population	0.8	0.4	1.9	8.9	59,940,000
Dairy cow population	5.5	0.3	0.1	0.9	2,232,000
Beef cattle population	1.3	0.4	0.7	2.4	4,549,000
Crop area	0.4	0.1	1.4	11.4	1,339,000 acres

* Based on data applicable to the 1966-1969 period.

Table 6. Computations involved in the calculation of weighted rainfall indices in the South Canterbury/North Otago region. Data for March 1969.

Climatological Station	Rainfall % of normal	Land A*	Area B**	Human Population A*	Human Population B**	Sheep Population A*	Sheep Population B**	Dairy Cows in Milk A*	Dairy Cows in Milk B**	Beef Cattle Population A*	Beef Cattle Population B**	Crop A*	Area B**
Lake Coleridge	54	1.1	59.4	0.1	5.4	1.7	91.8	0.0	0.0	0.3	16.2	3.0	162.0
Ashburton	39	1.2	46.8	0.8	31.2	2.5	97.5	0.2	7.8	0.4	15.6	11.0	429.0
Lake Tekapo	97	2.8	271.6	0.1	9.7	1.3	126.1	0.0	0.0	0.5	48.5	1.6	155.2
Timaru Aerodrome	68	0.8	54.4	0.4	27.2	1.1	74.8	0.3	20.4	0.4	27.2	3.2	217.6
Timaru	48	0.3	14.4	1.2	57.6	0.7	33.6	0.1	4.8	0.1	4.8	2.4	115.2
Waimate	40	1.4	56.0	0.3	12.0	1.9	76.0	0.1	4.0	0.7	28.0	5.0	200.0
Tara Hills	89	1.2	106.8	0.1	8.9	0.7	62.3	0.0	0.0	0.2	17.8	0.7	62.3
Oamaru	74	1.2	88.8	0.9	66.6	1.0	74.0	0.1	7.4	0.2	14.8	4.0	296.0
South Canterbury/ North Otago Region		10.0	697.2	3.9	218.6	10.9	636.1	0.8	44.4	2.8	172.9	30.9	1637.3
Weighted Index (B/A)		$\frac{697.2}{10.0} = 70$		$\frac{218.6}{3.9} = 56$		$\frac{636.1}{10.9} = 58$		$\frac{44.4}{0.8} = 56$		$\frac{172.9}{2.8} = 62$		$\frac{1637.3}{30.9} = 53$	

* A - Percentage of the New Zealand total of the economic parameter located in the geographical county and associated climatological station(s).

** B - (Column A) x (the rainfall at the climatological station expressed as a percentage of normal).

Table 7. Climatic indices* for various areas in New Zealand** weighted according to the significance of various economic parameters. Data for March 1969.

	Area	Economic Parameters											
		Land Area		Human Population		Sheep Population		Dairy Cows in Milk		Beef Cattle Population		Crop Area	
		A	B	A	B	A	B	A	B	A	B	A	B
1	Northland	15	9	11	8	17	8	16	8	16	8	14	10
4	Waikato	27	1	35	1	26	0	27	1	26	1	26	1
7	Hawke's Bay	31	17	31	20	30	14	32	10	31	15	29	14
11	Manawatu	42	15	46	15	36	14	48	16	38	14	41	14
14	Nelson	12	5	10	9	11	6	8	8	12	6	10	8
15	West Coast	104	0	95	0	95	0	82	0	108	0	85	0
17	North Canterbury	27	25	20	29	27	26	27	27	26	26	29	26
21	Southland	124	1	124	1	127	1	127	1	126	1	128	1
	North Island	28	9	25	10	25	9	25	6	27	9	31	12
	South Island	79	11	57	18	81	14	60	14	75	14	69	18
	New Zealand	58	10	35	13	52	11	27	7	36	10	62	16

* A = rainfall index (normal = 100)

B = days in month with water deficit

** Selected areas only

Table 8. New Zealand monthly rainfall indices weighted according to various economic parameters : 1966/67 - 1969/70

Season	Month	Land Area	Human Population	Sheep Population	Dairy Cows in Milk	Beef Cattle Population	Crop Area
1966/67	7	106	110	117	123	130	107
	8	84	83	92	84	95	100
	9	74	85	67	118	87	43
	10	63	61	67	55	64	85
	11	130	139	128	131	131	131
	12	126	138	144	152	166	104
	1	96	95	85	100	86	84
	2	102	140	112	172	137	82
	3	119	128	110	152	124	97
	4	116	81	100	64	80	116
	5	80	78	85	74	68	97
	6	43	44	46	43	48	41
1967/68	7	64	54	55	64	58	45
	8	136	138	130	147	130	123
	9	77	99	82	91	86	78
	10	73	52	75	41	68	84
	11	211	214	189	213	184	214
	12	117	118	125	141	142	89
	1	68	70	68	51	57	90
	2	70	59	63	45	47	84
	3	120	97	103	82	76	145
	4	185	250	201	201	191	259
	5	117	117	106	130	113	90
	6	145	144	144	155	154	143
1968/69	7	100	94	105	78	98	123
	8	106	101	92	119	106	73
	9	101	85	95	91	87	95
	10	130	112	126	119	123	108
	11	88	80	79	86	78	84
	12	114	134	124	161	147	100
	1	103	112	106	111	100	104
	2	92	106	91	151	129	56
	3	59	35	52	27	36	62
	4	97	101	99	91	96	98
	5	93	102	96	99	92	98
	6	73	69	72	83	78	55
1969/70	7	56	52	54	52	55	50
	8	78	80	79	89	82	64
	9	124	105	93	123	99	80
	10	67	53	70	41	58	81
	11	61	58	60	73	75	48
	12	148	138	149	153	145	151
	1	85	68	86	43	68	109
	2	60	47	62	37	68	62
	3	146	158	158	153	166	150
	4	62	61	62	60	61	58
	5	93	116	106	113	113	95
	6	99	103	90	106	98	91

Table 9. Weighted* mean temperature indices for New Zealand. Indices are differences from the 1931-60 normals in ^{o}C.

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1954	0.4	1.4	1.2	-0.7	0.9	1.3	0.3	-0.1	-0.2	-0.5	1.6	0.7
1955	0.6	1.8	1.1	1.2	1.6	-0.3	-0.4	0.8	0.6	1.0	0.2	0.9
1956	2.4	0.5	-0.4	3.0	1.1	1.3	0.5	0.1	0.5	0.8	0.3	0.2
1957	0.6	1.4	1.4	0.8	0.9	0.4	-0.5	0.8	0.3	-0.7	-0.1	-0.9
1958	-0.6	1.5	1.3	-1.0	0.3	0.3	-0.4	0.3	-0.4	1.5	0.9	1.3
1959	1.3	0.1	0.6	0.1	-1.9	-0.7	0.3	0.3	0.6	-0.7	0.3	0.8
1960	0.8	0.2	-0.8	-0.4	0.7	0.6	0.4	-0.3	0.5	0.8	0.0	-1.0
1961	0.1	0.2	-0.5	-0.0	-0.1	0.2	0.1	-0.4	-0.2	1.7	0.5	1.6
1962	2.0	0.2	0.5	0.3	2.2	1.3	1.0	0.6	0.3	1.6	0.4	0.2
1963	0.7	1.3	-0.1	-0.1	-0.0	-0.2	0.3	-0.7	0.2	0.6	-0.8	-0.6
1964	-1.0	0.2	0.1	-0.3	-0.6	0.1	1.4	0.2	-0.0	-0.1	-0.2	0.8
1965	1.3	-0.8	-0.2	-0.2	-0.2	-0.0	-0.9	-0.2	0.3	-0.9	-0.6	-0.1
1966	0.2	1.9	1.1	0.2	-0.9	-0.1	0.0	-0.9	-0.1	-0.2	-0.6	-0.4
1967	-0.4	-0.3	0.7	0.3	0.4	-0.7	-0.0	1.7	-0.4	1.0	-0.0	0.6
1968	-0.2	0.1	2.7	0.2	0.9	0.7	-0.2	0.6	-0.6	-0.6	-0.7	-0.7
1969	-0.1	-0.6	0.1	-0.6	0.3	-0.8	-0.7	0.3	1.5	-0.9	0.9	1.9
1970	1.9	0.3	1.4	0.9	-0.6	0.8	1.2	1.1	0.9	0.9	0.7	1.1

* Weighted according to the distribution of the human population.

Table 10. New Zealand monthly "water deficit" indices (days per month) weighted according to various economic parameters: January 1969 - April 1970.

Year	Month	Land Area	Human Population	Sheep Population	Dairy Cows in Milk	Beef Cattle Population	Crop Area
1969	1	2.9	2.1	3.3	2.8	2.9	3.6
	2	1.7	1.1	1.7	1.6	1.5	2.0
	3	9.0	7.7	8.3	7.7	8.2	9.6
	4	5.3	5.5	6.8	5.5	6.1	7.0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0
	7	0	0	0	0	0	0
	8	0	0	0	0	0	0
	9	0	0	0	0	0	0
	10	0	0	0	0	0	0
	11	0.8	1.8	0.9	1.3	1.0	0.8
	12	0	0	0	0	0	0
1970	1	5.4	4.4	5.2	4.4	5.1	5.6
	2	19.3	19.8	20.8	21.1	20.4	21.4
	3	4.5	5.8	5.9	5.5	5.3	5.8
	4	0	0	0	0	0	0

Table 11. Weighted climatic indices for New Zealand

Year	Month	Climatic Index: Rainfall* (100=normal)	Water deficit** (days)	Temperature*** (^{o}F)
1969	Jan.	103	1.8	-0.2
	Feb.	92	2.3	-1.0
	Mar.	59	7.2	+0.1
	Apr.	97	3.7	-1.0
	May	93	0.1	+0.5
	June	73	0.1	-1.4
	July	56	0.1	-1.3
	Aug.	78	0.1	+0.5
	Sep.	124	0.1	+2.7
	Oct.	67	0.1	-1.6
	Nov.	61	2.3	+1.7
	Dec.	148	0.5	+3.5
1970	Jan.	85	5.8	+3.4
	Feb.	60	18.3	+0.5
	Mar.	146	6.6	+2.6
	Apr.	62	0.4	+1.7

* Weighted by land area

** Weighted by dairy cow population

*** Weighted by human population

Table 12. Butterfat processed by dairy factories in New Zealand* and associated climatic indices for New Zealand weighted according to the population of dairy cows in milk. January - April : 1966-1970.

Month	Year	Actual production (m.lbs)	Difference from expected (m.lbs)	Difference from expected $(m)**	Month (n-2) A	Month (n-2) B	Month (n-1) A	Month (n-1) B	Month (n) A	Month (n) B	(n-2)+(n-1)+(n) B
Mar	1970	30.5	-27.6	-5.5	43	6	37	18	153	7	31
Apr.	1970	20.4	-19.6	-3.9	37	18	153	7	60	0	25
Feb.	1970	46.3	-15.9	-3.2	153	1	43	6	37	18	25
Mar.	1968	43.0	-12.4	-2.5	51	2	45	14	82	12	28
Apr.	1968	35.6	-4.7	-0.9	45	14	82	12	201	1	27
Jan.	1970	72.4	-4.6	-0.9	73	2	153	1	43	6	8
Apr.	1969	36.2	-4.5	-0.9	151	2	27	7	91	4	13
Feb.	1968	56.4	-2.2	-0.4	141	0	51	2	45	14	16
Jan.	1967	70.8	-0.8	-0.2	131	0	152	0	100	1	1
Apr.	1967	40.0	-0.8	-0.2	172	1	152	2	64	2	5
Mar.	1969	56.5	-0.5	-0.1	111	2	151	2	27	7	11
Jan.	1966	68.2	-0.4	-0.1	131	0	123	1	133	1	2
Apr.	1966	37.1	-0.2	-0.0	185	2	111	2	109	1	5
Feb.	1969	60.2	-0.2	-0.0	161	0	111	2	151	2	4
Jan.	1969	75.9	-0.2	-0.0	86	0	161	1	111	2	3
Feb.	1966	54.3	+0.4	+0.1	123	1	133	1	185	2	4
Jan.	1968	75.0	+0.9	+0.2	213	0	141	0	51	2	2
Mar.	1967	54.3	+1.3	+0.3	100	1	172	1	152	2	4
Mar.	1966	51.7	+1.5	+0.3	133	1	185	2	111	2	5
Feb.	1967	57.9	+1.6	+0.3	152	0	100	1	172	1	2

* In order of difference from the "expected" production
** Based on a net return to farmers of 20 cents per lb

A = Rainfall index (normal = 100)
B = Water deficit index (days in month shown)

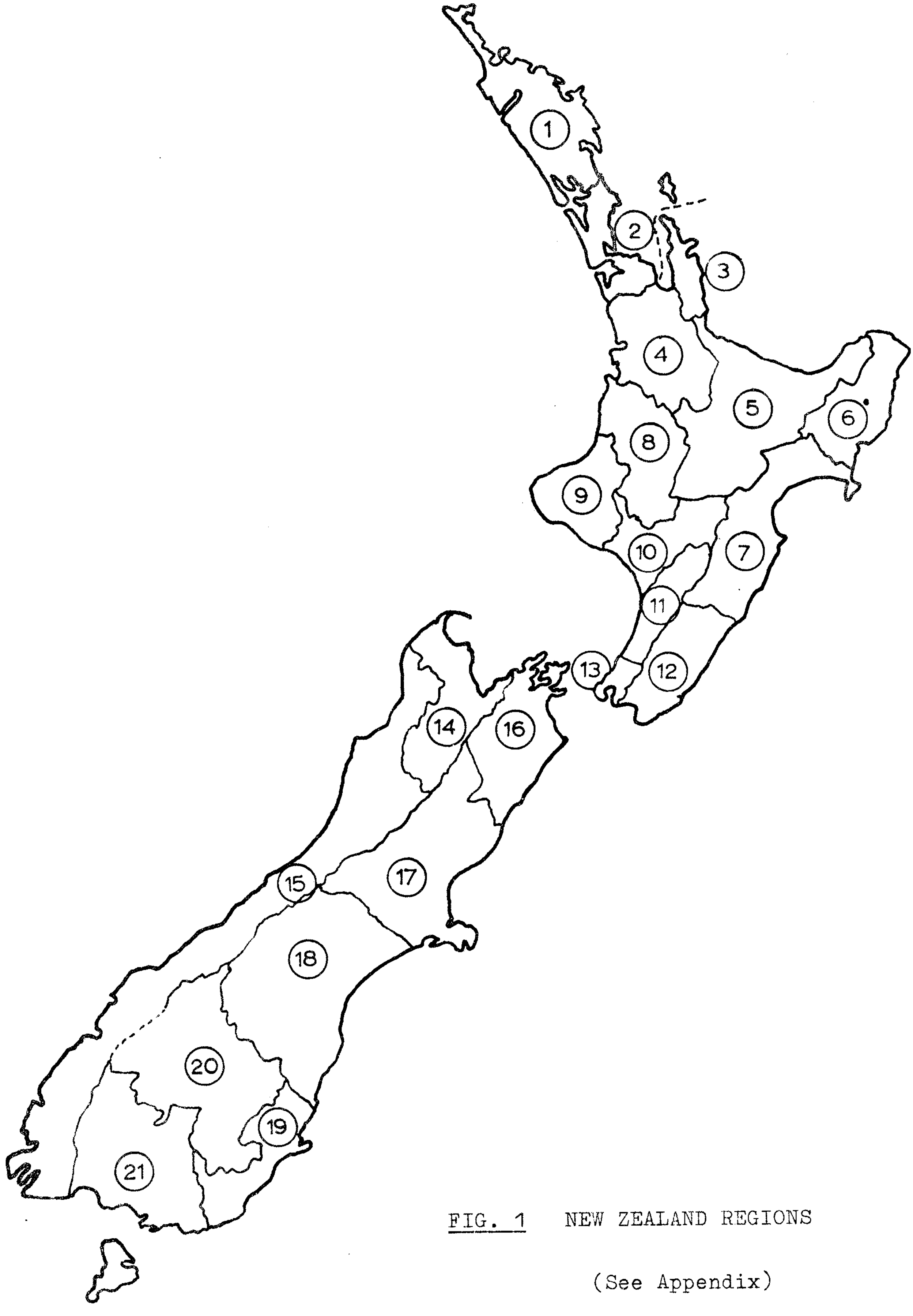
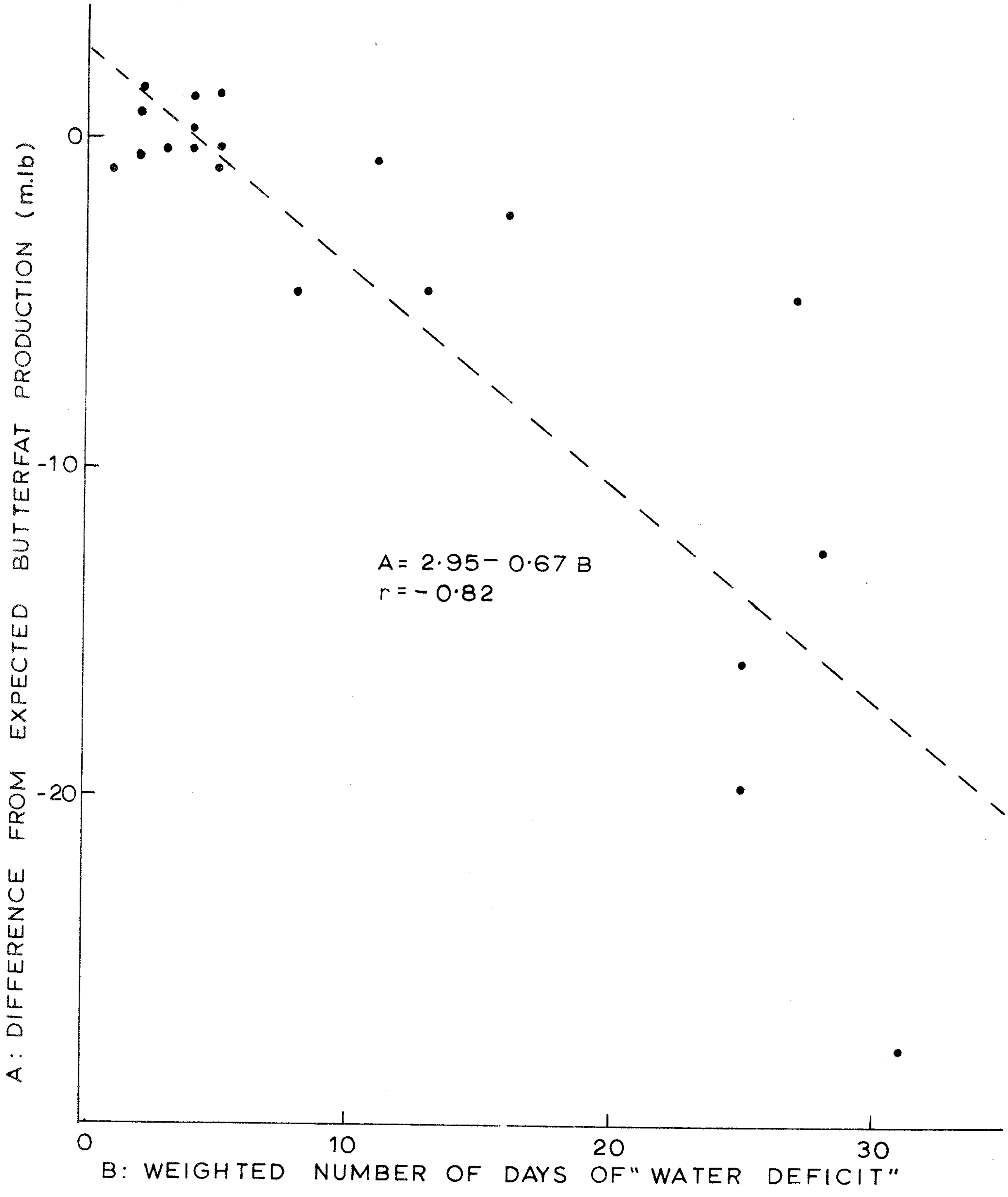


FIG. 1 NEW ZEALAND REGIONS

(See Appendix)



<u>FIG. 2</u> MONTHLY NEW ZEALAND BUTTERFAT PRODUCTION AND ASSOCIATED WEIGHTED "WATER DEFICIT" INDICES JANUARY - APRIL : 1966 - 1970

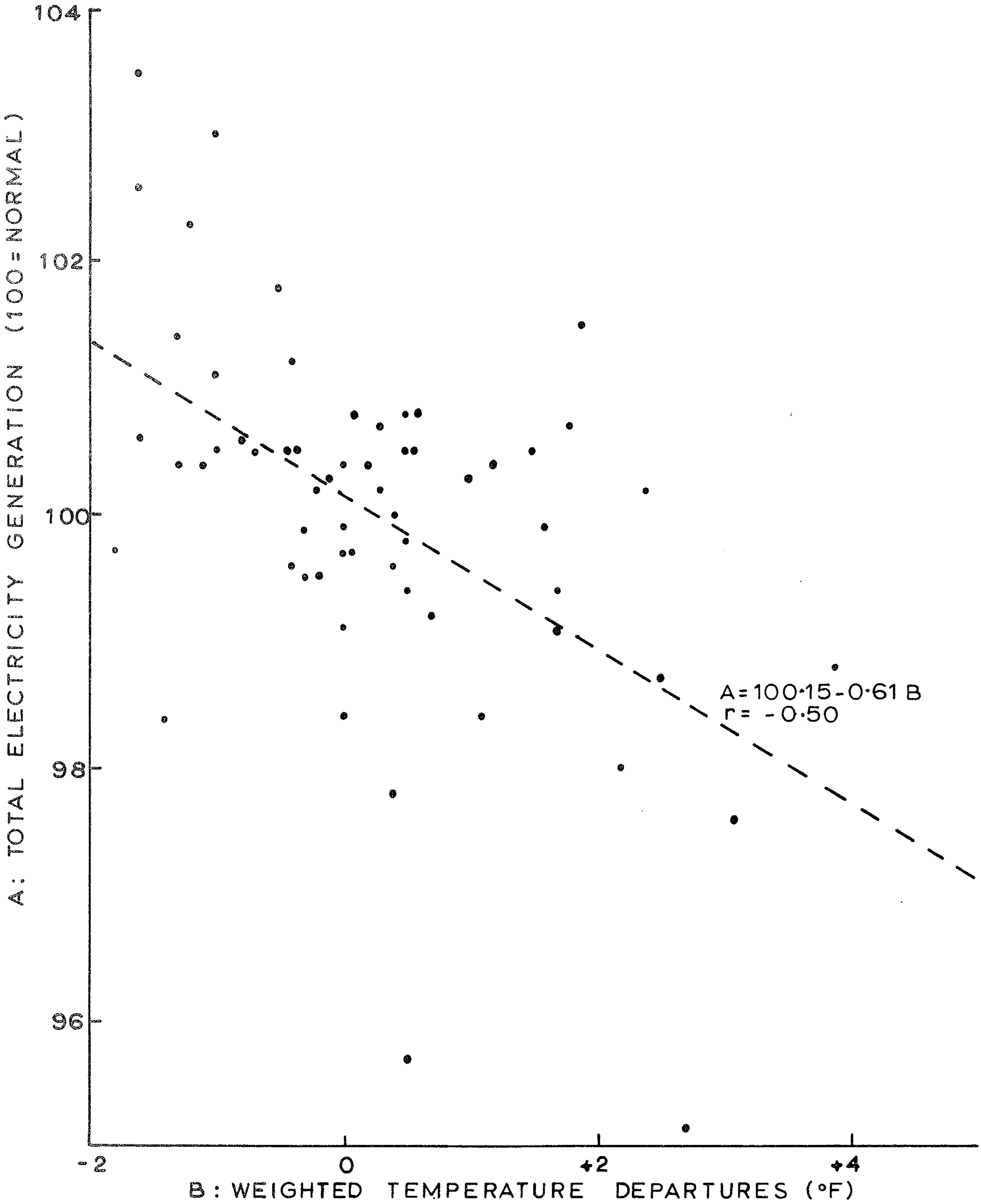


FIG. 3 MONTHLY NEW ZEALAND ELECTRICITY GENERATION AND ASSOCIATED WEIGHTED TEMPERATURE DEPARTURES APRIL - SEPTEMBER : 1961 - 1970