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THE POSSIBILITIES OF LONG-RANGE WEATHER FORECASTING IN AUSTRALIA

by

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SUMMARY

The nature of a long-range weather forecast is defined. The methods which are available are discussed and the use which is made of them in Australia. Suggestions are made for the setting up of a long-range weather forecasting unit in Australia.

TABLE OF CONTENTS

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1. INTRODUCTION.

Most of the material in this article will be familiar to meteorologists and other scientific workers. In fact, no new material is presented, nor does the author claim to be working in the forecasting field. However, long-range weather forecasting is of interest to most people and any real success with it would be of profound importance to the national economy. It is discussed freely by the press and there are many self-appointed weather prophets who claim skill in this difficult field. In fact, it is doubtful whether there is any other subject which attracts so many enthusiastic amateurs and professed but unqualified experts, each performing to his own satisfaction and quoting successful examples to prove his skill, but conveniently forgetting his failures. Unfortunately the few triumphs of the amateur are often ranged against the few failures of the professionals. It is therefore thought that an informed opinion, couched in relatively simple terms may serve a worthwhile purpose and enable a better judgment to be made of the topic. It might also be possible to settle long existing doubts as to whether it is possible or worthwhile for Australians to attempt research and to make progress in this subject. Potential avenues of research are described and may be judged by the reader. It is with these intentions that this brief review of long-range weather forecasting is given.

It should also be pointed out that, as well as gathering together this material, opinions have been sought from persons active in meteorology and associated sciences. These opinions have been digested and the views expressed here are those formed from such discussions and reading.

2. WEATHER FORECASTING.

At this early stage it is as well to consider why weather forecasting is such a difficult science, or perhaps an art, and why it is subjected to more criticism than almost any other subject. We might then better appreciate the role of the meteorologist and the nature of the forecasts which he issues. It is very much in its favour that weather forecasting is accepted by the community as an established technique and considerable funds are now applied to its practice. In fact, the national weather services devote the larger part of their budgets to networks, weather forecasts and improvement in forecasting methods.

2.1 Success and Failure.

In spite of this very considerable effort and expense, weather forecasting has achieved only moderate success according to Willett (1951) who said that "Probably there is no other field of applied science in which so much money has been spent to effect so little real progress as weather forecasting". From the perfectionist's standard this may be true, but occasional forecast failures must be set against the many successes. Decisions requiring knowledge of future weather have to be made frequently, and when loss of life or financial risk is involved, an informed opinion, if followed over a period, must achieve better results than disregard of the weather situation. On this criterion alone the weather service returns immensely more to the community than is invested in it. Also the increased safety of travel which has resulted from improved weather forecasts, has proved the value of the Bureau of Meteorology.

Although the meteorologist is termed an applied scientist, he must admit that when he attempts weather forecasting, he cannot fully express the weather process in scientific terms, nor can be extrapolate it to the future as a pure scientist might expect to do. In weather forecasting there is a strong subjective element which is closely associated with the forecaster's experience and personal skill, and until it is replaced by qualitative factors will always give uncertainty in prediction. Like an engineer, the meteorologist is faced with the necessity of giving a decision for the future on inadequate data and knowledge. However, even granting this, his informed opinion is better than nothing, and in the long run proves very valuable. As has been mentioned, the many successes must be set against occasional failures. Furthermore, complaints about wrong weather forecasts imply that they are usually correct. There is no doubt that if decisions involving weather phenomenon are made with the professional help of a meteorologist, greater success is attained or losses are cut to a minimum, particular if these are taken over a period.

In support of this, Priestley (1963) states:-

> "And there are many fields of activity, notably in primary industry where advance decisions have to be made in the light of expectations for the coming season; 'black or white' predictions based on even a small advantage of probability, or shade of odds in betting parlance, must be better than no information at all provided the odds are stated."

2.2 <u>Forecast Period.</u>

Weather forecasting accuracy is related inversely both to the length of period predicted, and to the precision with which the future weather is described. As the weather forecast is extended in time so the detail that can be given about the future weather decreases and the chances of the forecast being correct diminishes. Thus forecasts of weather a few hours ahead are both detailed and successful, but if more than a few days are attempted they become vague and subject to failure. The increasing efficiency of the weather service in forecasting over the past 10 years is not always appreciated as when greater detail and accuracy are achieved over the short term forecast there is a demand for more detail and longer range forecasts with the same degree of accuracy. Persons commenting on the accuracy of forecasting for aircraft during the last war compared with today's newspaper forecast are making precisely this error. An aircraft forecast is essentially of short range over a specified route and can be described precisely. The regional forecast published in the press, covers a much longer period of time and describes, as well as possible, the range of weather expected over the period in question and over the region which may have diverse physiographic features.

2.3 Accuracy and Verification.

The accuracy of a forecast is mentioned glibly above, but verification of any weather forecast is not easy. Forecasts are usually given in general terms such as cold, hot, rainy, (subjective terms), and not in quantitative terms such as temperatures of 70 or 60 degrees, rainfall of 1 inch, (objective terms). Where objective terms are given, verification is easier and nowadays the tendency is to use this technique. A forecast also describes a number of meteorological elements, temperature, humidity, precipitation and wind, and, although these are inter-related, the forecast may be right for some one element, but not for the others described. Also each of the elements varies with time and over an area. The variations of weather within short distances can be remarkably complex and baffling. The weather is also much more changeable in some latitudes than others. All of these factors make it difficult to describe the expected weather in an area, to verify this against the actual weather and to give an estimate of the forecasting accuracy. Forecasts which define weather carefully in time and space, particularly if in objective terms, can be verified more easily and a figure of accuracy obtained. This, of course, decreases as the time interval extends. For example, some generally accepted figures for accuracy of forecasts are given by Willett (1951) and are repeated here. Very short range (12 hours) forecasts are successful 90 to 95% of the time. Short range (12-48 hours) forecasting accuracy varies from 70 to 90%; for 2 to 7 day forecasts of precipitation, the accuracy may be little better than 60%. For long-range forecasts (exceeding 7 days ahead) there is only conjecture, but forecasts of a month ahead have claimed 55-60% accuracy. With the progress made in the last 12 years these figures may now be higher.

Although the long range forecast in general in its termsit must also be clear and easily understood. For example, attempts have been made to verify the unofficial lone-range weather forecasts published in the Australian press from time to time. These efforts were made difficult by the need to interpret the vague terms used and to find out what weather was predicted to occur and in what place. It was only after such an interpretation was made that the forecasts could be compared with the weather which did occur. In fact, the more vague the forecast the easier it was to claim success. On some occasions it was impossible to deduce a definite prediction. It was also found that some periods forecasted, not only overlapped but were contradictory, and so one of them would have to be correct. This might be claimed as the meteorologists' right to change the forecast because of new weather developments. However, these particular forecasts tested gave no better accuracy than that due to chance. Unfortunately, there was a tendency to draw attention to those forecasts which were correct and forget those which were not, and use them as evidence of correct long-range weather forecasting.

One of the most frustrating aspects of long-range weather forecasting is that each of the many methods appear to achieve some success at one time or another but none over the whole spectrum of data. It may be that the experienced forecaster, or weather watcher, intuitively or deliberately selects periods to suit his theory or sees a pattern and then speculates on the causes. Perhaps a simplicity is assumed in action and interaction which only shows up in some periods when other effects are in phase or dormant. Perhaps, when all the significant factors are known they may be blended to give a comprehensive system.

McIntosh (1958) draws attention to the view that there may be an "unpredicability" element in the development of weather systems, as is now accepted of individual cumulus clouds. This would mean that chances are small of increasing the precision of weather forecasts or of extending their range except in general terms. Although this may be true of minor weather phenomena, it does not apply to large scale changes in the circulation and weather pattern and is unnecessarily pessimistic.

The accuracy of weather forecasting will always be disputed and will certainly vary from one year to the next and with location. One fact is highlighted however, namely, that difficulties increase immensely as one extends the period of forecast beyond one week. However, the return which long-range weather forecasting could give the community, with even a low degree of accuracy,is so high that it should not be lightly discarded. The intention is therefore to examine the long-range weather forecasting problem, to discuss the claims of some systems which purport to be successful, to refer to other known systems and to assess the prospects of using these successfully in Australia.

2.4 The nature of a long-range weather forecast.

It follows from above that a long-range weather forecast will be general in its terms, and usually covers a month or a season. It will deman d some latitude in respect of time, i.e. the start or finish of a predicted event cannot be precisely given. There will also have to be some permissible variations in the weather over an area although if areas can be defined where weather is homogeneous, these areas will become the forecast zones. The most important element to predict is precipitation, although its random nature in some districts may give doubts as to whether it is a suitable parameter to use in the analysis of part records. Next important may be temperature, although as its departures from normal are more systematic, perhaps definition of the temperature regime should proceed particulars of the precipitation field.

Unless the weather follows a very steady seasonal pattern, as in some tropical regions, it is not possible, from the very nature of weather phenomenon, to give a precise forecast for a particular day some period ahead. Persons who attempt precision forecasts on this day to day basis, weeks, months, or years ahead are deluding themselves and their clients. It is not sound to extrapolate one's knowledge of the climatology of a place to the year in question and to assume that weather on a particular day can be given a precise description. It is presumptuous enough to speculate concerning major weather movements without assuming a knowledge of the day to day fluctuations within those major movements. Some so called long-range weather forecasters, in doing this for a fee, condemn themselves and throw doubt on the validity of their methods.

A similar fallacy is to match one series of years, say using annual rainfalls, with another series of years distant some years away, called the cycle, and then to assume that not only do the annual rainfalls match, but the sequence of events within individual months or even on particular days will match those within the former weather period. This assumes a simplicity in the factors causing weather that does not exist. A popular description of the precipitation process much less a scientific one, should convince anyone of its complicated nature and our ignorance of many facets of it, especially the initiating mechanism and the impossibility of predicting its occurrence at a particular time and place, weeks ahead.

On the other hand, weather shows many broad variations in which there may be a pattern:- wet and dry spells; hot and cold periods; droughts and floods. It is rare that a month or season conforms to normal. Furthermore, temperature and precipitation are not unrelated and any long-range forecast should consider both elements. A modest aim is therefore to indicate whether the coming season or month, is above or below normal. Also, wide deviations from the normal weather have profound effects and there is such great value in warnings of flood or drought that, to this aim, we might add an indication as to whether large departures from normality are likely or not.

The extent and location of the forecast area is relevant and must be defined. It must also be reasonably homogeneous. In defining such areas climatology can be of assistance. However, besides average conditions, variability is significant. If the weather at a location usually shows large variations, from day to day or, from month to month, then the seasonal departures from normal are not as significant as if they occurred in locations of more regular climates. It may thus be preferable to use the less variable data of these latter regions in long-range forecasting rather than higher variable data. In Australia Loewe (1948) has shown that data from stations in the far north and far south are less variable than the stations in between, and thus may be more suitable for the type of analysis we are considering.

A long-range weather forecast, therefore, should give a general estimate of precipitation and temperature as above or below normal, and, preferably, whether much or little above or below average. It should cover at least a month with extension to the coming season and apply to a reasonably homogeneous area. These limiations are accepted by those seriously attempting long range forecasting. Success may be judged on the extent to which the predictions, in these terms, are realised. Monthly forecasts of this type have attained accuracies of 60% by objective tests.

It is fortunate that many professed long-range weather forecasters give forecasts of greater precision and detail than can possibly be achieved from the very nature of the problem. It is suspicious that accuracies greater than 60% are claimed for such forecasts and, invariably, only a few cases are quoted in justification. Factual assessments of the accuracy of published unofficial long-range weather forecasts in Australia have been made at Melbourne University and the Bureau of Meteorology and have not confirmed the claims of the professed forecasters. The results of the tests have not been published nor are they generally known to the public who are therefore not in a position to judge the value of such work.

Petterssen (1964) draws attention to the importance of the worldwide atmospheric circulation in the forecasting problem. He states that "the atmosphere is an open system of a thermally active substance which behaves in response to inputs of solar energy and interactions at the earth-atmosphere interface." Therefore long-range weather forecasting in particular is not a regional problem and must be related to the global circulation and the entire system of processes within the atmosphere. It follows that, above average rainfall in the westerly belt, might be associated with a dry period in the sub-tropics. One aim should therefore be to establish satisfactory relationships between the weather of different latitudes. If this were done, long-range forecasts for one area might be extended and related to many other areas. An immediate implication is that international co-operation is necessary. This is emphasised in the recent report of the World Meteorological Organisation (1961) which suggests not only the exchange of data, forecast texts, and scientific papers but calls for international co-ordination in the future development of methods. There is every prospect that this will be achieved.

3. METHODS IN USE FOR LONG-RANGE WEATHER FORECASTING.

3.1 Introduction.

A number of ex cellent surveys of long-range weather forecasting have been written or published by D.H.McIntosh (1957); R.C. Sutcliffe (1962)! The World Meteorological Organisation (1961) and The American Meteorological Society in the Compendium of Meteorology (1951). For detailed technical information on the methods under trial the reader is referred to these surveys and more particularly to the references they contain. A brief summary only is given here with comments on their applicability to Australian conditions.

The methods are commonly classified under the following three headings for convenience in discussion, but they are all interrelated and have ultimately a common physical basis, although this may not be obvious at first.

3.11 The Synoptic-empirical Approach.

In this method surface or upper weather maps (synoptic charts) may be classified into types, analogues may be found, and the present pattern related to the average conditions or the general circulation.

3.12 The Physical-mathematical or Numerical Approach.

This approach attempts to describe the processes of the atmosphere in terms of mathematical equations and, by approximate methods and computers, to solve these equations.

3.12 The Statistical Approach.

In this method weather data is analysed by statistical techniques to detect correlations, cycles, trends and singularities.

Each of these will be considered in further detail below.

3.2 The Synoptic-empirical Approach.

Since the turn of the century, weather or synoptic charts have been the classic tool of the forecaster and are used in all short range weather forecasts. The surface and upper level maps give a basis of extrapolating the wind and pressure fields ahead for about two days, and, and in favourable circumstances to five days. From the predicted wind and pressure distributions the closely related weather is forecast.

It is not surprising therefore that these synoptic charts should be a starting point in long-range weather forecasting and that work in this field has been done in most countries. The mean patterns, usually for 5 days, of the pressure fields over at least a hemisphere are determined and types identified. The detailed features which may be important in short range forecasting are suppressed, so that the overall circulations ("gross-wetter") are apparent. By classifying these from past records, examining their evolution and persistence, the present pattern is extrapolated for at least 5 days and up to a month or so ahead. Research has shown the existence of so called "natural" circulation regions (five in the northern hemisphere) as well as "natural" synoptic periods (6 days). Allied with this is the identification of waves and their periods. The appearances and persistence of anomalies or departures from the usual seasonal weather pattern or the general circulation are particularly significant.

Some success in this method has been achieved both in Europe and the United States where the national meteorological services are continuing work on this approach, see (W.M.O. 1961). This work could be extended to give the global circulation but would require improved networks and co-operation. Prospects of this being achieved are excellent.

In using synoptic charts a short-range weather forecaster seeks to recall similar past situations and uses them as a help in predicting weather. This is known as the analogue method and is also adopted to long-range weather forecasting. The use of computing machines can replace memory and gives a sound basis to such a method. However, it is not easy to define our present weather situation by a precise model in three dimentions, with an allowance for season. Measurements of the weather with height is also comparatively recent (last 30 years) which means we have only a very limited length of record in which we might find suitable analogues. These two factors restrict the use of this method.

The large amount of work which has gone into the synoptic methods has not been in vain. Besides increasing our knowledge of the general circulation it has enabled forecasts of 5 to 30 days to be produced and these have had better than mere chance success. A conservative estimate of their success is 60% and there is further potential.. It demands, however, considerable staff and analysis on a hemispheric basis. Most work so far has been done in the northern hemisphere. Because of the greater proportion of sea to land and the absence of marked topography in the region of the westerly air flow in the southern hemisphere, it is likely that here a more regular pattern may be maintained and anomalies and variations easier to separate. Against this the large expanse of southern ocean and lack of settlement gives far less data than is available in the northern hemisphere. With the establishment of observing points in the Antarctic, Australia is already taking a hand in investigations of the southern circulation.

It is as well to note that the use of the synoptic chart at the turn of the twentieth century changed the whole emphasis of meteorology. Many natural scientists at this time were showing interest in the periodicity of weather phenomena and relating it to extra-terrestrial influences but, with the setting up of synoptic networks , weather science was dominated for the next fifty years by synoptic meteorology. Some forecasters still tend to explain weather in terms of isobars instead of the processes leading to the pressure changes and variations and have made meteorology a technology with its own particular jargon and techniques instead of a basic natural science of interest to all scientists. In some ways, therefore, synoptic meteorology may have held up advances in other avenues over the first half of this century. However, the general upsurge in research into space and other fields since the war has stimulated thought into the more fundamental processes and in recent years meteorology has been pursued on a much broader front.

3.3 The numerical or physical-mathematical approach.

It is a common technique in science to express physical processes in terms of mathematical equations which the scientists hope to solve. Attempts have been made to apply this method to the processes within the atmosphere and, with time as a variable, solve such equations to give weather forecasts. This sounds deceptively simple, but involves very great difficulties.

Unfortunately the fundamental processes within the atmosphere are not fully understood or measured. Simplified models can be set up to describe these processes but omit important factors or require data which are not measured to the required accuracy nor are possessed of any length of record. Such omissions and limitations become more serious for the extended periods of long-range weather forecasting.

The use of the most simplified models gives equations which are too complex for complete solution. High speed computers now permit approximate numerical methods to be used and it is possible by starting from some initial condition to obtain estimates at some time ahead from the equations. Over short periods some success has been achieved in this field of numerical weather forecasting.

At the present time these simple models and the derived equations do not describe the atmospheric processes well enough; nor are the solutions sufficiently precise to make this a worth while method of long-range weather forecasting. However, our knowledge of the fundamental processes is advancing as is our capacity to handle more complicated mathematical expressions. There are prospects that soon, the atmospheric field of motion may be more adequately described and extrapolated so that successful long-range forecasts may be achieved. As with the synoptic approach, the current work is greatly increasing our knowledge of the general circulation or the atmosphere and, on this ground alone, merits continued study.

The approach is considered very promising although no figures of accuracy are as yet available. The emphasis on space research, satellites, and rockets during the last decade is giving more data and is acquainting more scientists with the physics of the atmosphere. Under such conditions progress in this field can be expected.

3.4 The statistical approach.

The fundamental processes of the atmosphere and their relationship to the incoming and outgoing radiation are difficult to express in precise terms as has been explained above. However, this has not hindered the collection of extensive meteorological data which has been done, in a quantitative form, for about 200 years, and in a qualitative way, from historical records, for several thousands of years. These statistical data form the bases for much scientific research irrespective of the factors which have caused these changes.

From earliest times, besides observing nature and measuring its phenomena man has tried to see a pattern or plan behind its vagaries. Early in history, the planetary bodies conformed to his notions of regularity and he worked out and predicted their movements and interactions. It was a logical approach to extend these ideas to the variations of weather and attempt to forecast it in a similar way to the movement of the heavenly bodies. There is no doubt that connections exist but whether these can be established and used is not so certain. In the long-range weather forecasting problem, therefore, one of the earliest and simplest approaches was to examine the mass of data which had been collected and, with no deep regard for the processes which caused them, to attempt to deduce trends, cycles, patterns, correlations and connections. This is termed the statistical approach and has interested invididuals of varied talents and professions besides the official forecasters and government organisations.

Data have been analysed in many different ways. These have varied from the simple plotting of the data and visual deductions of relationships and patterns to extensive modern statistical techniques such as time series, auto correlation, Fourier analysis, theory of extreme values, Monte Carlo methods and spectra analysis.

There are two necessary steps in statistical analysis. Firstly the selection of the parameters which are to be analysed and secondly the statistical techniques to be used.

The commonest parameter to select is that of rainfall, although temperature and pressure are also frequently used. It is apparent immediately that these parameters may not show the same variation at different locations. In fact, high or above average rainfall at one station might quite easily be associated with low or below average rainfall in other latitudes or longitudes. For this reason the selection of a parameter to measure the general atmospheric circulation is more appropriate and so the position and intensity of the high pressure or anticyclonic systems, or conversely, the low pressure systems have been used as appropriate parameters by many workers. The inward, outward or nett radiation might also be logical elements to use in analysis but unfortunately such data has not been collected for a long period nor at a sufficient number of stations.

Statistical techniques are numerous. The best known is that of cycles or periodicities and work varying from simple graphs to complicated computer programmes have revealed many cycles. In fact so many cycles have been revealed that almost any period may be shown provided there is tolerance in fitting and selection of data. This is confusing and leads to self deception. Again the technique of using running means may show certain trends and cycles, but also conceals the variation of the years comprising the running mean. It is also obvious that some of the cycles demonstrated may fit one or two sets of data but cannot be fitted to all the data with confidence. Mainly on the basis of the coincidence of two sets of 34 years of rainfall records, Inigo Jones concluded that he had discovered a basic cycle but because the whole series of years do not fit into this cycle one must conclude that it was merely a coincidence. Any such work to be accepted should be based on valid statistical methods. This would eliminate most of the mathematical exercises of amateurs.

Many workers have also attempted to associate any discovered periodicities with solar activity or planetary motions. For example, the sunspot variation is known and associated with weather phenomenon and relationships have been established. This does not assist the forecast problem greatly unless we are in a position to forecast variations in solar activity or the sunspot cycle. Also, the influence of the planets and moon on the solar output or balance has not been established "a priori" although statistical tests have found similar periods in these to the weather. This is not sufficient to link the two phenonmena and further measurements and analyses must be done before any real relationship may be claimed or used.

Correlation is another statistical technique which has interested weather forecasters. In particular lag correlations have been used with some limited success as is evidenced in the work of Walker (1930). Grant (1956), however, concluded that the correlation coefficients were not sufficiently high for practical use. In fact this extensive statistical work at Melbourne University on long-range weather forecasting had negative results and it was stated that "the observed correlations themselves provide no evidence for the existence of real correlations of useful magnitude".

Recent work by Priestley (1962), using association coefficients, show that progress in this field is possible. A fully co-ordinated application of these methods to other Australian data, using punch cards and computers should be well worth the effort.

Associated with the synoptic approach one can use statistics to analyse many of the anomalies and singularities which show up over wide areas. Anomalies in temperature and rainfall may be fitted into a pattern useful to forecasters particularly in the medium range field. The coming of the monsoon in North Australia and the breaks of the season in southern Australia might, if examined statistically, give correlations, cycles or series.

Some very useful work has been done on climatic change. It is difficult to attribute causes to such changes but the statistics of Kraus, Brooks and Lamb show that climatic changes have occurred. If these trends can be associated with other physical phenomena they might be used in long-range forecasting.

So far, however, efforts have been concentrated on detecting the trends and theorising on the causes. More positive verification of the causes and establishment of valid relationships are necessary before such methods are useful.

In the statistical approach we are watching even less than the shadows on the wall. We require further knowledge of the nature and intensity of the extra terrestrial radiation and its interaction with the earth and its atmosphere. Changes in radiation might be linked with the upper circulation and the general (lower) circulation of the atmosphere but more specific information and measurements of these are required. Such research can be immensely expensive as is evident from the present United States and Russian space programmes which are producing some of the desired information. This data should be fully exploited in meteorological research and Australia should be working in this field. Australia may not be in a position to initiate an elaborate programme of rocketry or satellite research but it has facilities at the Long-range Weapons Research Establishment and in C.S.I.R.O., particularly in the Divisions of Radio-Physics and Meteorological-Physics to make some impact on the problem. Financial assistance in these fields should be well worth while. This should not only add to fundamental knowledge but help with long-range weather forecasting problems. As mentioned earlier Australia's position in the general circulation of the southern Hemisphere may make this problem more amenable to solution here than at other places in the world.

One advantage of statistical methods is that an individual using published meteorological data, and mathematical skill can do some work on the problem in his spare time. In other ways this is a disadvantage in that we have enthusiastic amateurs "discovering" cycles and correlations which may apply for one set of data but not for others. Their work does not stand up to the stringent tests of modern statistics. There is a need for a strong statistical section in a long-range weather forecasting project so that many of these "discoveries" can be examined and proved or disproved. For example a sound scientific analysis of the so called "Inigo Jones cycle" should be made and published. It would enable both professional men and laymen to see the weaknesses and failures of the system or its strengths and accuracies.

The punch carding of meteorological data and the use of sorting machines and computors should enable a very thorough statistical analysis to be done with a minimum of labour and should be put in hand. It should also be possible to bring statistical methods into the other methods of long-range forecasting and strengthen all of them.

It is impressive that statistical methods have attracted the attention of so many distinguished scientists. This indicates that their considerable experience and ability have discerned some connections and that further effort is merited.

4. LONG-RANGE WEATHER FORECASTING IN AUSTRALIA.

4.1 Introduction.

The considerable variability of Australian weather was obvious and pointed out by the early observers and it is not surprising that attempts were made to fit patterns into these variations. As these observations were generally made under the supervision of the astronomical observatories it also follows that this early work was statistical and related to planetary movements. Some interesting coincidences were observed by Russell (1896) who correlated droughts with the lunar cycle of 18-19 years. Although no great success was achieved in prediction this was followed up by Jensen (1956) and anticipated the recent work by the Division of Radio-Physics of C.S.I.R.O. on lunar influences.

It is unfortunate that little has appeared on long-range weather forecasting in Australian scientific journals until somewhat recently. A paper by Radok (1953) describes the position well, but it is not readily available. The Commonwealth Governmental committees which were set up to look into the subject also did not publish their findings and accordingly left it very much "up in the air" and open to false claims of success and newspaper inaccuracies.

It has therefore been necessary to discuss much of the Australian work with the persons concerned and although clear statements in scientific terms could be obtained from the workers in the government organisations and universities, the same could not be said of the others. Any worthwhile system must obviously be capable of explanation and adoption by others to give similar results. From these discussions an interpretation of the methods is given and an assessment of the success which has been achieved.

4.2 The Synoptic-empirical approach.

In the United States and Europe the synoptic empirical approach has been used with some success by Namias, Baur, Multanovsky and many others. For extending the range of present forecasts to beyond 5 days and up to 30 days it has merit and uses recent weather information. Special world wide data (climate reports) extend the scope of these investigations which are best undertaken by the national meteorological bureau.

On a very limited scale, in Australia, work in this field is being done by Karelsky (1961). He has determined the "anticyclonicity" and the "cyclonicity" or "the time in hours during which anticyclonic or cyclonic centres occupy a given 5° square during a given period (4-5 days, ½ month, 1 month, season or year)." By referring these current values to average conditions he has prepared 30 day forecasts which have had about 60% success. As this work has been done by one man only it is creditable and should be carried further with more staff. Its weakness is that little account is taken of upper air data and approximately one eighth of the southern hemisphere is considered. Over a wider area, preferably world wide and with upper air data in addition to surface data, still more useful forecasts might be issued.

Any long-range weather forecasting investigation in Australia on the synoptic method should entail the global circulation as Australia is located in the subtropics and is influenced by air currents from both hemispheres. In higher latitudes the westerly flow may be the dominant control but this is not so near the equator where there are regular incursions of northern hemisphere air into Australia.

4.3 Physical-mathematical approach.

In Australia little systematic work is proceeding on the physical-mathematical approach, although there are many individuals interested in the physics and mathematics involved and have given considerable thought to aspects of the problem. In the southern hemisphere the atmospherical circulation is relatively unimpeded by major land masses or high mountain ranges, and the circulation pattern could be somewhat simpler than in the northern hemisphere. This suggests it may be well worth while exploring this field in Australia for it is not rigidly separated from the other methods which are being tried. The lack of detailed observing points in the Southern Hemisphere is of course an adverse feature. There is merit however in further emphasis on the physical-mathematical approach for the purpose of theoretical training and for practical extension to forecasting. Application to shorter range forecasting is the first step but with increased experience and knowledge the periods might be extended with prospects of ultimately using the method for long range weather forecasting.

Those familiar with synoptic charts in the Australian region would agree that pressure systems can be remarkably constant over long periods. Also on the different occasions but at the same time of year these pressure systems do differ significantly, indicating that there are considerable changes in the circulation pattern. This gives hope of finding reasons for the changes and using them as means of forecasting the future circulation.

Radok (1953) makes suggestions as to "the prognosis of time space circulation patterns" but considers a physical approach in which more data, especially for the upper levels, would be necessary. The strong interest however at Melbourne University and the Division of Meteorological Physics in the general circulation indicates that any Australian forecasting unit would secure support and assistance from them in this method.

As earlier pointed out, this technique cannot be separated from the others, in fact, a more thorough understanding of the mathematics and physics of the atmosphere is necessary for a full appreciation of the other techniques which must ultimately rely on a physical basis.

4.4 The statistical approach.

Much weather data are readily available in publications and it is not difficult to apply some mathematical techniques to them. Consequently the statistical approach to long-range weather forecasting has attracted many workers and has been a fruitful source of research for individuals, both professionals and amateurs. It is interesting to note the number of prominent scientists, not all being meteorologists, who have become interested in long-range weather forecasting, almost as a hobby. Added to this are the hosts of enthusiasts who spend their spare time attempting to fit a system into the diverse weather patterns. It may be as innocent a pastime as jig saw puzzles but can mislead its adherents as a chance coincident of a pattern may be translated as a recurring event.

There was an early interest in long-range weather forecasting in Australia. The work of H.C. Russell (1896, 1901) on the moon's effect on weather was novel and is acquiring new significance now in the light of the recent works of Adderly E.E. (1963) Bigg E.K. (1963) and Bowen E.G.(1963) on lunar influences on physical phenomena.

At the turn of the century Wragge in Queensland was interested in long-range weather forecasting and his inspiration and work were carried on at Crohamhurst by Inigo Jones who became a notable public figure. There is no doubt that Jones' exceptional personality aided and abetted by newspapers more interested in a good story rather than truth, set up a myth of successful long range weather forecasting which was not supported by fact, and which could have retarded serious advances in the field.

In attempts to verify or deny the claims of Inigo Jones, there were set up at least three committees comprising prominent scientists. None of the reports of these committees were made public. One can only conclude that they were unfavourable.

A long-range forecasting Trust was set up to assist with the financing of Inigo Jones' work, but has now been dissolved. As well as money it provided staff to Jones who either did not find their technical or personal qualities satisfactory or disillusioned them to the extent that they did not continue working with him.

Dr. H.I. Jensen of Caboolture was research director of the Trust for some years and examined the methods and wrote a paper (1956 unpublished) which is probably the best factual summary of them. He states that through the hundreds of tests which he made of each of the cycles "all were found quite unsatisfactory". He considers that seasonal forecasting on scientific lines is possible and calls for "a bureau with three or more scientists collaborating to study planetary movements, sunspots and other solar and lunar phenomena and periods, contemporary meteorology of other parts of the world, changes of ocean level and currents and many other matters".

The Bureau of Meteorology also sent a meteorologist to Crohamhurst in 1953 to examine the methods. His report also has not been released but it should be noted that he did not continue with the work, nor has the Bureau adopted any of Jones' methods.

Although Dr. Jensen's paper is the best factual summary of cyclic influences on weather and the work of Jones, the Crohamhurst observatory also has had numerous publications which it provided to subscribers. These publications contained statistical data obtained from the Bureau of Meteorology and were useful in assessing climate. The descriptive material mentions cycles chiefly the Bruckner, of about 35 years, although a Double Bruckner of 71 years was apparently the one that Inigo Jones found most satisfactory. He claims to have verified this period from Brisbane rainfall records and attributes the variations to planetary movements chiefly those of Jupiter with an orbital period 11.9 years (one third the Bruckner period).

Sunspot activity is also related to these movements and is observed and used as a forecasting aid. Inigo Jones' physical reasoning is theoretical only and is not supported by data and cannot be accepted by modern physicists. The statistical techniques used are crude and show coincidences at certain periods but not at others.

It is possible that there is a relationship between solar and planetary movements and the weather, but this will have to be established with better statistical methods and supported by sound physical theory. This may involve new measurements. The over optimistic claims and unfounded statements that have been made from Crohamhurst however, verge on self-deception, test the patience of scientists and bring long range forecasting into disrepute.

The work of Inigo Jones is being carried on at the present time by Mr. Lennox Walker who emphasizes sunspots which he observes regularly and uses as the basis of his forecasts. These forecasts have not proved any more accurate than those of his predecessors. A more balanced view of long-range weather forecasting may have been acquired by the public if the reports on the activities of the Crohamhurst Observatory had been published. The published matter available to me from this institution was found neither scientific nor accurate.

Among other people who have been interested in long range weather forecasting is G.W. Nowland of Casino, N.S.W. He published a book on the subject but this contains many unsupported statements and information contrary to modern physics. Other long range forecasters use the height of tide and different planetary movements. It is the rule that we hear much of their occasional successes and nothing of their many failures.

It could be that there are some planetary influences in weather - possibly lunar, solar, and planetary cycles operating on an atmosphere which varies in properties. These periodicities when in phase, may tally with some of the cycles mentioned by Jones. The sun and moon also have a proven effect on the tide and thus tidal heights may be a measure of their influences. One should therefore not dismiss the efforts of these workers entirely but should endeavour to find the scientific truth within their sincere work.

The recent work of Adderley (1963) Bigg (1963) and Bowen (1963) on lunar influences is significant and gives hope that some connections may ultimately be established between weather and planetary movements. It is refreshing to note that in these approaches more modern statistical techniques are being used and attempts are made to measure phenomena (freezing nuclei, atmospheric ozone etc.) as well as seeking explanations on sound physical lines for the many effects. It may happen that many of the miscellaneous cycles and effects which have been discovered or mentioned and which occasionally show remarkable coincidences or promise as long range forecasting tools, may be explained by reference to lunar and solar influences acting on an atmosphere which also shows variations in its properties. These properties may be of a random nature such as the amount of volcanic dust in the atmosphere or persistent effects wuch as extensive snow or water cover on the continents or cloud systems in the atmosphere leading to disturbance of the normal radiation balance.

Recently (1963) in personal discussions, Jensen claimed that all planetary influences might have been disturbed or obscured by volcanic activity in Indonesia. The wide distribution of the dust from this eruption and its persistence in the atmosphere for many months could quite reasonably have influenced the heat balance of the earth and so the weather. Any forecasts based only on planetary motions might thus be invalid.

The Bureau of Meteorology has not neglected the statistical approach, in fact it has taken an active interest for some time. The work of Quayle (1930) and Treloar (1934) was followed by the setting up in 1949 of a small research unit in conjunection with the Department of Meteorology at the University of Melbourne. This unit made use of the multiple correlation technique exemplified by the work of Walker (1930). A number of reports were issued and Grant (1953, 1956) showed that the multiple correlation coefficients derived were not consistent and varied according to the data used. She concluded that it was doubtful "that this correlation approach could supply a basis for a satisfactory method of long range forecasting even for the tropics where the day to day variations were small, let alone for higher latitudes where the short term changes dwarf those in the means".

In spite of this unfavourable conclusion, Priestley (1962,1963) has used lag association coefficients and has shown that relationships may be established which might be of use in long range weather forecasting. Further work in this field is warranted and should be undertaken.

Interest in the statistical approach has also been shown by Hannan (1962) who, in an examination of rainfall singularities, showed that significant cycles could be detected within a year. More effort could be concentrated in this direction as well and might reveal or disprove suspected periodicities. Modern statistical techniques should be used to test cycles which were discovered by simple graphical methods, guesswork, fitting of curves by eye, instinct or, "black magic". Such action is n ecessary to establish their veracity or otherwise. If this is not done, these cycles will continue to hold an unwarranted status which has been gained by hearsay and word of mouth.

5. CONCLUSIONS.

At present, long-range weather forecasting in Australia is neither sufficiently accurate nor reliable enough for use in business or agriculture. The occasional successes must be balanced by the failures which are almost as numerous. No evidence can be found to substantiate claims of accurate weather forecasting over periods in excess of five days. No more than 60% success was discernable in any system and most were not much better than guesswork.

A report by the World Meteorological Organisation (1961) indicates that overseas countries are exerting more effort on the problem than Australia, even allowing for population differences. Many of the overseas nations use all approaches described while Australia is concerned, and in a small way, with the synoptic and statistical approaches only. The concensus of opinion among meteorologists is that methods of long-range weather forecasting are promising and worth continuing. Many countries now issue regular monthly forecasts. Some success, 60% or slightly better over 30 days, is claimed with the synoptic approach. The physical mathematical is considered the most promising attack for the future and is attracting the greatest amount of attention at present.

Peterssen (1964) has pointed out that knowledge of the general circulation and techniques of handling data with computers are advancing rapidly and that it should be possible "to keep the whole of the atmosphere under surveillence and process vast volumes of data on a real time scale". This means that there are real prospects of significant breakthroughs in the long-range forecasting field.

Australia with its dependance on primary industries and its location within the highly variable subtropics has so much to gain from successes in long-range weather forecasting that it cannot afford to neglect the subject. Most of Australia is in a low rainfall area, marginal for most primary industries, and suffers severe drought and flood. Furthermore, its lack of contrasting topography between prevailing wind streams suggests a minimum of interference with the general circulation and greater homogeneity in data compared with other continents. Any prediction of the overall pattern should be easily interpreted in Australia. A properly constituted long range forecasting unit should be set up or reconstituted and strengthened as an urgent matter. The team should work on all phases of the long-range problem in collaboration with universities, CSIRO and overseas services. Full use should be made of the data processing and computing facilities of all organisations. In view of the charter of the Bureau of Meteorology and the data and facilities it controls it is the logical instrumentality to set up and launch a full scale attack on the problem. To date there is only the dedicated work of a few enthusiasts. The unit should be portion of the Bureau's Research section but freed from routine and in close contact with other interested bodies. In assessing the size of such a unit a minimum of six scientists is suggested for a start with ancillary help estimated to double the number.

Although the statistical approach in Australia has been tarnished by the work and publicity of non-professionals, it should not be discarded on this account. It is an attractive technique when the data is handled objectively and with regard to physical principles. Some impressive work is under way in C.S.I.R.O. within the Divisions of Meteorological Physics and Radio Physics. Some surprising results might come forth.

The question of parameters might be reconsidered by a long-range weather forecasting unit. At present the most commonly used parameter is that of rainfall, as it is the element which it is desired to predict and long and consistent rainfall records are available. Its random nature and variability however limits its usefulness and may lead to false conclusions, depending on what stations or data are employed in an analysis. Perhaps pressure or temperature are more appropriate indicators of the large scale circulation changes. Jensen, Karelsky and others have used integrated values of pressure by referring to the latitudes of the moving anticyclones and measures of "anticyclonicity" or "cyclonicity". This may be a more appropriate measure and is easily related to the precipitation and temperature pattern. It is pointed out that if weather is to be related to the energy input or output and this is assumed to depend on planetary motions there will always have to be a parameter giving the condition and content of the atmosphere. Terrestrial occurrences such as volcanic eruptions, atomic explosions, persistent cloud banks or changes of surface colour and the increased consumption of fuel may affect the properties of the atmosphere either in a random fashion or as a trend. Such influences would need to be superimposed on a prediction based on, say, the periodic motions or activity of the sun, moon or planets. For example, the recent eruption (1963) in Bali was said to have rendered a forecast of a dry year in Queensland invalid by the addition of volcanic ash which affected the radiation balance and freezing nuclei count.

On the other hand, if the time lag and effect of such a phenomena were known then this could be superimposed on an original weather statement and could modify the forecast. The careful selection of parameters is an early matter for any long-range weather forecasting project.

Long-range forecasting should be done on a global scale rather than on a regional basis. For example, a forecast of increasing westerly winds would imply an intensification of the subtropical high pressures which in turn may suggest an additional surge in the tropical monsoon. That is, above average rainfall in the equatorial and temperate belts may be associated with below average rainfall in the subtropics. It follows that any Australian research unit would need to co-operate with other nations. In fact long-range forecasting is more truly an international problem than any other with the maximum achievement following full co-operation. The World Meteorological Organisation undoubtedly offers the avenue here for co-ordination. In fact Australia's isolated position in the southern hemisphere places an additional international responsibility upon her, not only to maintain a suitable network but to provide men with the training and background to collaborate in the world wide long-range forecasting problem.

The setting up of the Antarctic stations shows that Australia is willing and able to fulfil part of this obligation, but full use should be made of the data obtained. A long-range forecasting unit would undoubtedly be concerned with the circulation in these latitudes very early in its history and would make full use of this information and apply it to the Australian region. It would also advise on the establishment of other observing posts or the obtaining of more detailed information.

Perhaps oneof the first contributions of an Australian long-range forecasting unit might be to determine the relationships between the weather at places in Australia in respect to the global circulations. Priestley (1963) is anticipating this with the use of association correlations which he states provide "mainly an identification and starting point for studies of a more detailed and critical nature in which more flexible methods of synoptic classification and meteorological etc. judgment are fully brought to bear".

The extensive space programme of Russia and the United States gives prior knowledge of the state of the upper atmosphere. This and the availability of high speed computers in these countries gives unassailable advantages in predicting changes or variations in the general circulation. However, if and when this is done, international collaboration through the World Meteorological Organisation should enable our meteorologists to fit Australia into this forecasted circulation. This is not yet apparent, but the data of satellites and other space probes are giving increasing knowledge of atmospheric motions and hope for improved predictions. Even without this anticipated development there is sufficient important work to keep an Australian forecasting unit fully occupied for many years.

In discussions on the setting up of a long-range forecasting unit all considered that it was worth while. In fact, all were in favour of a sizable effort. Because of its existing pool of data and meteorologists, the Bureau of Meteorology was the logical home of such a unit provided close collaboration was maintained with universities and C.S.I.R.O. Key personnel, however, may have to be recruited at a high level. It would not be wise to initiate this type of work without a number of informed personnel. Alternatively it may be necessary to send suitable graduates overseas for several years to gain experience with the techniques. There is merit in the Bureau requiring higher academic qualifications in those persons it allots to this work, or giving them the opportunity to acquire such qualifications in the progress of their work. The most able and highly qualified should find the task worthy of them. The returns to Australia are so high that considerable investment in the project is well worth while.

The report of the World Meteorological Organisation (1961) states that 15 member countries are regularly issuing long range weather forecasts in the sense discussed here. The Director General of the British Meteorological Office also announced (1964) a reorganisation to facilitate regular forecasts and continuing research in the extended range field. J.M. Craddock (1964) gives recent details of work in the U.S. Weather Bureau. The report of Baum and others (1959) shows that the Soviet Union is well aware of the significance of the work. At a conference of Commonwealth Meteorologists in May 1963 also, "it was agreed that the issue of reliable long-range forecasts was the greatest contribution the meteorologist could make to a nation's economic welfare. Progress in this field had shown little sign of significant success but this must not cause a slackening of research and experiment".

It is apparent from the above statements that long-range weather forecasting has to be taken seriously and that Australia is justified in setting up a sizable unit to continue research into and to prepare and issue long range weather forecasts. Adequate facilities and competent and sufficient staff are the prime requirement and it is not so much a question as to whether Australia can afford it, but rather that the nation cannot afford to neglect a subject of such vital importance to her welfare.

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