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AN INCREASE IN THE SKILL OF AUSTRALIAN TEMPERATURE FORECASTS

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ABSTRACT

Australian temperature forecast verification data are analysed with a view to establishing the existence or otherwise of trends in the skill displayed by the predictions. The data examined are for late afternoon forecasts of the next day's maximum and minimum temperatures issued to the public of the six Australian State capitals over the period 1964 to 1979 inclusive. It is concluded that the skill displayed by these predictions increased, on the average, over the period under consideration.

INTRODUCTION

During the early 1960s, the Bureau of Meteorology commenced a systematic program of verifying temperature predictions issued to the general public. The program, which is still in operation, involves the verification of late afternoon forecasts of the next day's maximum and minimum temperatures at major population centres. Verification data are available for the period 1964 to date for the six Australian State capitals - Hobart, Melbourne, Adelaide, Sydney, Perth and Brisbane (Fig. 1). The aim of this paper is to present an analysis of these data* with a view to establishing the existence, or otherwise, of long-term trends in the skill displayed by the predictions. Throughout the paper, the root mean square error (r.m.s.e.) of a set of predictions is employed to represent the level of accuracy of that set of predictions. Few data are available on the accuracy of public forecasts of weather elements other than temperature in Australia. However, temperature prediction statistics do give 'an indication of overall forecasting capability' (Neal 1977).

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*There is doubt about the accuracy of the data for a small number of months at several capitals (Perth maximum - one month; Brisbane maximum - three; Sydney minimum - one; Perth minimum - one; Brisbane minimum - one). These months are confined to the early part of the record. They were excluded from the analysis presented in this paper but it is not considered that their exclusion adversely affects the validity of the paper's findings.

ANALYSIS OF DATA

The temperature data are summarised in Fig. 2, which depicts year to year fluctuations in the annual r.m.s.e. of all temperature forecasts (maximum **and** minimum) at the six capitals. Figure 2 suggests that there was an increase in the overall accuracy of temperature forecasts over the period under consideration. To illustrate - only one of the r.m.s.e.s for the latter six years was above the mean annual r.m.s.e.

Forecast accuracy is a function of **both** forecasting skill and forecast difficulty. Hence, year to year fluctuations and long-term trends in the accuracy of temperature predictions may be entirely due to corresponding fluctuations in the level of difficulty associated with the estimation of that element. An analysis of the relationship between forecast accuracy A and forecast difficulty D was then made in order to test the validity of this proposition. The relationship was assumed to be linear and of the form

$$A = C_0 + C_1 D \quad \ldots 1$$

where C_0 and C_1 are constants.

Gregg (1969) notes that temperature forecast errors increase with increasing temperature variability. For each of the 16 years from 1964, D was set equal to the annual root mean square inter-diurnal change (r.m.s.i.) of all temperatures (maximum **and** minimum) at the six capitals and A was set equal to the annual r.m.s.e. Applying these data, the constants C_0 and C_1 were found by regression analysis to be 1.3621 and 0.2577 respectively. The 't' distribution was then used to show by means of a one-tail test (Yamane 1973) that the regression coefficient C_1 is significant at the 0.6 per cent level, that is, the probability of C_1 being as large as, or larger than, 0.2577 by chance, is less than 0.006. It was therefore concluded that a strong relationship exists between r.m.s.e. and r.m.s.i.

Equation 1 was then solved to determine the **expected** value of r.m.s.e. for each of the 16 years. Year to year fluctuations in the parameter 'expected r.m.s.e. **minus** observed r.m.s.e.' may be considered, at least in part, to be a consequence of corresponding fluctuations in predictive skill. Forecast skill may be considered to increase with increasing values of this parameter and, conversely, to decrease with decreasing values. The year to year fluctuations in the parameter are presented in Fig. 3 and provide evidence in support of the proposition that the skill displayed by the temperature forecasts increased over the period under consideration.

The significance of this apparent increase in forecast skill was then investigated. The relationship between forecast accuracy A, forecast difficulty D, and time T was assumed to be linear and of the form

$$A = C_2 + C_3 D + C_4 T \quad \ldots 2$$

where C_2, C_3, and C_4 are constants.

For each of the 16 years from 1964, A was set equal to the annual r.m.s.e, D was set equal to the annual r.m.s.i., and T was set equal to

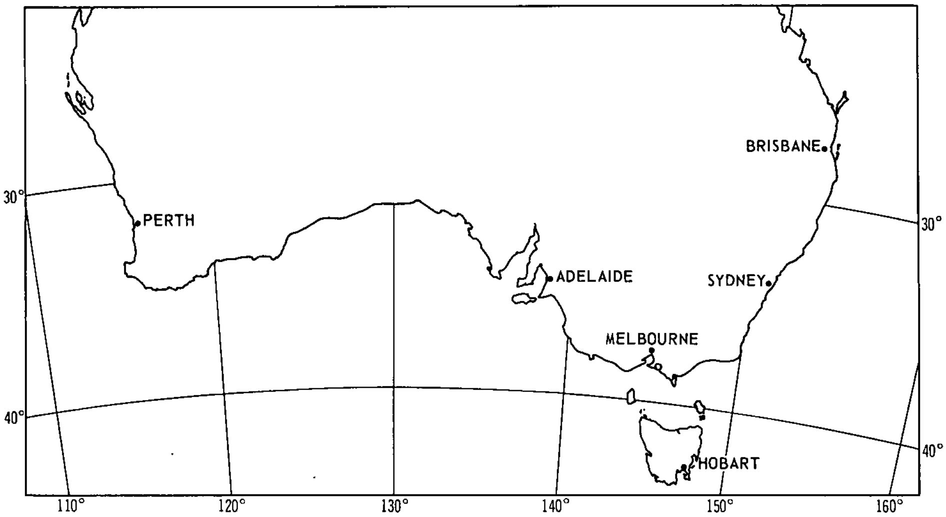

Fig. 1 Location of the six Australian State capitals whose temperature predication data are analysed.

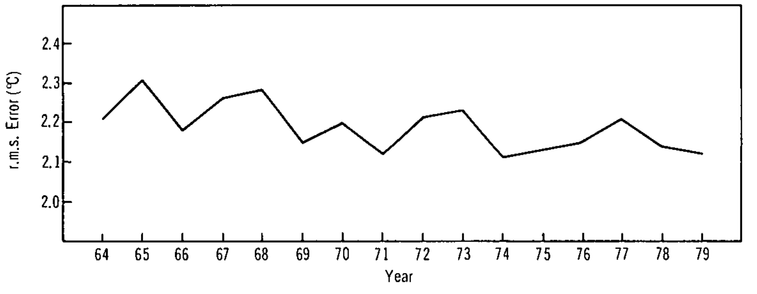

Fig. 2 Year to year fluctuations in the r.m.s. error of all temperature forecasts (maximum and minimum) at the six Australian State capitals over the period 1964 to 1979 inclusive.

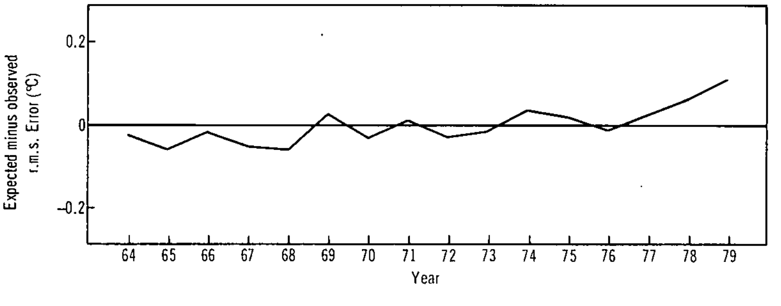

Fig. 3 Year to year fluctuations in the departure of the annual r.m.s. error of all temperature forecasts at the six Australian State capitals from that expected using Eqn 1.

(year - 1964). The constants C_2, C_3, and C_4 were then found by regression analysis to be 1.4335, 0.2533, and -0.0076 respectively. Using the 't' distribution, it was found by means of a one-tail test that the partial regression coefficient C_4 is significant at the 0.06 per cent level, that is, the probability of C_4 being as small as, or smaller than, -0.0076 by chance, is less than 0.0006. Now $C_4 = \frac{\delta A}{\delta T}$ and may therefore be regarded as a measure of the rate of change of skill. It was therefore concluded that the overall skill displayed by late afternoon predictions of the next day's temperatures at the six capitals increased, on the average, over the period 1964 to 1979. Moreover, it was found by means of a one-tail test that the partial regression coefficient C_3 is significant at the 0.05 per cent level. That C_3 should be found to be highly significant is not unexpected as calculations for both C_1 in Eqn 1 and C_3 in Eqn 2 are based on data from the same period. However, the finding is in further support of the use of annual values of r.m.s.i. to represent forecast difficulty.

DISCUSSION

Satellite cloud imagery and numerical predictions of atmospheric flow both became available to operational meteorologists during the period under consideration. In particular, during the late 1970s the output of the Australian Region Primitive Equations (ARPE) model (McGregor et al. 1978), GMS imagery at three-hourly intervals, and buoy data over hitherto data-sparse areas also became available. It appears likely that the increase in skill is partly a reflection of the value these additional aids are to the solution of the forecasting problem - see Downey et al. (1980) for an evaluation of MSL prognoses produced by the ARPE model,and Hicks et al. (1979) for an analysis of the impact of buoy data on forecasting in the Victorian region.

In order to ascertain what were the specific contributions to the overall improvement in temperature forecasting, C_4 was determined for each of the twelve temperature forecasts under consideration (Hobart maximum, Hobart minimum, Melbourne maximum, etc.) by separately analysing the data associated with each of these forecast elements. Values of C_4 and their levels of significance are presented in Table 1.

The data in Table 1 suggest that the main contributions to the overall increse in skill displayed by Australian temperature forecasts came from Hobart, where there were significant increases in skill at predicting both minimum and maximum temperature; from Melbourne, where there was a significant increase in skill at predicting maximum temperature; and from Perth, where there was a significant increase in skill at predicting minimum temperature. Although the values of C_4 associated with the other forecast elements are relat[illegible]ly insignificant, it appears that overall, skill increased at a great[illegible] rate at middle-latitude locations than it did at subtropical locations. [illegible]o illustrate - the six C_4 at the three more poleward capitals (Hobart, Melbourne and Adelaide) are all negative whereas only three of the six C_4 associated with the other capitals are negative.

Table 1 Values of C_4 and their associated levels of significance

City	Forecast	C_4 (°C per year)	Significance level (only given where 10% or less) %
Hobart	Maximum	-0.0271	0.4
	Minimum	-0.0134	2.0
Melbourne	Maximum	-0.0129	6.0
	Minimum	-0.0056	
Adelaide	Maximum	-0.0046	
	Minimum	-0.0080	
Sydney	Maximum	-0.0060	
	Minimum	+0.0042	
Perth	Maximum	+0.0001	
	Minimum	-0.0190	0.05
Brisbane	Maximum	+0.0008	
	Minimum	-0.0001	

One would expect the aids referred to earlier to have a greater impact on the forecasting of temperature at the capitals of higher latitude for the following reasons. Firstly, regarding satellite imagery and buoy data, this information has enabled more accurate specification of frontal zones to the south and southwest of the continent and the need to specify the location of these fronts, for the purpose of predicting temperature, diminishes as one moves northward. Secondly, regarding the advent of numerical predictions of atmospheric flow and their subsequent development, knowledge concerning the dynamics of tropical circulations is 'relatively primitive', whereas a 'reasonably satisfactory theory' exists about middle latitude synoptic systems (Holton 1972) and hence these numerical predictions would be of benefit primarily to the capitals of higher latitude.

Before closing, the significant increase in skill displayed by Perth minimum temperature predictions requires explanation. Meteorologists in the Perth Regional Forecasting Centre (Lamond - personal communication 1978; Lynch and Southern - personal communication 1979) have attributed improved minimum temperature forecasting at Perth to the development of an objective aid specifically for minimum temperature forecasting during the summer months, and to closer attention being given to various aspects of the prediction of this element.

CONCLUSION

It has been shown that the skill displayed by late afternoon predictions of the next day's maximum and minimum temperatures at the six Australian State capitals increased, on the average, over the period 1964 to 1979. It is sugested that the advances in satellite technology, the advent of operational numerical predictions of atmospheric flow in this country, the receipt of buoy data from hitherto data-sparse areas, and a local increase in skill at specifically predicting minimum temperature at Perth, were factors in the improvement.

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