Predictability experiments with the Australian west coast summer trough

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The Australian west coast trough is the most important synoptic feature of the lower troposphere over southwestern Australia during the summer months. As such, its predictability is of great importance because inaccurate predictions of the location and strength of the trough can result in large temperature forecast errors in coastal and adjacent areas.

Both the numerical and manual operational forecasts issued by the National Meteorological Analysis Centre regularly fail to forecast accurately the west coast trough. This is attributable to an inability to account correctly for the major mechanisms controlling the movement and development of the trough, namely, land/sea thermal differentials, orography, and the positioning of neighbouring synoptic systems.

In this study, the operational numerical model has been enhanced by including a land/sea thermal contrast scheme; more detailed orography; higher vertical and horizontal resolution; and lateral boundary specifications from a hemispheric spectral model.

A large number (30) of forecasts were made with the improved numerical model on situations drawn from two consecutive summers. These forecasts exhibited a considerable increase in prognosis skill over the operational manual and numerical forecasts in the positioning and amplitude of the west coast trough.

Introduction

During each summer in the Western Australian region the so-called Australian west coast trough is the major feature of the surface synoptic charts, as evidenced by the sea-level mean pressure contours for January shown in Fig. 1. The precise location of this trough has a significant influence on the daily weather patterns of the southwestern regions of Western Australia, where the overwhelming majority of the State's population resides. However, as has been recently pointed out by Watson (1980), despite its importance the trough has been largely neglected as a subject of research.

The existence of a persistent surface trough near the Western Australian west coast had been noted early this century, but the first publications concerned exclusively with it did not appear until the 1950s when Gaffney (1955) pointed out the importance of the coastal trough in forecasting maximum temperatures for the west coast. Gaffney noted some characteristics of the trough, presented several detailed case studies, and suggested some formative factors. In particular Gaffney emphasised that deepening of the trough was facilitated by a conjunction of surface heating and divergence aloft. Gaffney also noted that during the deepening stages, maximum temperature forecasting was reasonably accurate because the sequence was gradual. Difficulties arose when the trough began to migrate eastwards. If it did so in the morning, Perth's maximum temperature would reach only about 27°C. However, if the trough did not move steadily eastwards until the afternoon, a maximum of at least 37°C would be expected.

There was little else written on the Australian west coast trough until the past few years. Annette (1978) published a brief note on the movement of the trough and expanded upon Gaffney's work in emphasising the importance of upper-level

Fig. 1. Mean sea level pressure normals for January based on Climate of the Upper Air (US Department of Commerce, September 1969).

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divergence associated with an eastwards moving upper trough. Watson (1980) recently has published a Ph.D. thesis which is by far the largest and most detailed study of the west coast trough to date. Watson extended the classifications of trough types catalogued earlier by Gaffney (1955) and Lynch et al. (personal communication) to eleven different types, based on various characteristics, such as whether it is offshore or inland; connected with a heat low or not; associated with a tropical cyclone; and so on. Watson also offers a dynamical explanation for the trough in which he identifies heat advection and upper-level divergence as the key components. According to Watson the Australian west coast trough is very much a three-dimensional system depending not only on surface and upper air patterns but also on neighbouring synoptic systems. Heat advection near the surface is enhanced when it is combined with favourable upper air divergence both of which in turn depend upon the positioning of other synoptic features around the coastal trough, such as the heat low, tropical cyclones and, perhaps most important of all, an offshore upper trough with its associated downstream divergence field. Watson did not discuss the role of orography, which is somewhat surprising as it can be easily shown (see for example McIntyre 1968) that easterly winds flowing off an escarpment will assume a cyclonic curvature.

Watson’s study of the Australian west coast trough was essentially climatological. However, in this paper we are more interested in its predictability as a day-to-day weather phenomenon. As has been mentioned already, although it is a climatological feature it can vary greatly in position, orientation and strength from day to day and therefore in its effect on weather in the southwest of Western Australia. An example of such a sequence is given in Fig. 2 which shows a succession of daily MSL charts for the week 1 to 8 January 1981. It is immediately apparent that, as Gaffney (1955) has already noted, the trough is capable of exhibiting both gradual and sudden changes, with corresponding consequences for local weather.

It is well known that numerical models and manual prediction techniques are most effective in forecasting systems that exhibit gradual or regular change. Indeed this is true of the west coast trough. Difficulties in forecasting usually arise when sudden or unusual changes occur. The main purpose of this paper is to show that an improved version of the operational numerical model is capable of predicting both regular and unusual developments of the west coast trough by including a representation of the main dynamical and physical ingredients of the trough. In this sense it is an extension of earlier work by McBride (1975) and Leslie (1980) which applied improved numerical models to enhance prediction of the summer heat low, with which the west coast trough frequently has an intimate connection.

Predictability characteristics of the Australian west coast summer trough

As mentioned in the ‘Introduction’, the Australian west coast trough has been classified by Watson (1980) into a number of different types. For the purposes of predictability we are less interested in the structural details of a particular trough than we are in its inherent ease or difficulty of prediction during the subsequent 24-hour period. Therefore we have decided to group the troughs on the basis of whether they are ‘classical’ or ‘non-classical’ in the sense that classical troughs exhibit regular behaviour over the ensuing 24-hour period whereas non-classical troughs show some kind of unusual or irregular behaviour. Obviously the classical and non-classical troughs will each contain a number of the types identified by Watson (1980).

The classical/non-classical dichotomy is, of course, intended to correspond in some way with the degree of inherent predictability. Classical situations should reasonably be expected to have a high level of inherent predictability, even if the trough changes considerably in position and strength during the forecast period. On the other
hand, non-classical situations would be expected to be more difficult to predict owing to an unusual development during the forecast period. In order to make the predictability discussion more concrete, consider the following examples of classical and non-classical warm season coastal troughs.

**An example of classical west coast trough development**

A fairly common sequence in the development of an Australian west coast trough is one in which a large and intense anticyclone with its track to the south of the continent progresses from the Indian Ocean into the Great Australian Bight. This usually takes place in the period extending from late spring through summer to early autumn, and provides an easterly wind regime over much of Western Australia; the easterlies may extend well into the troposphere if the anticyclone is very strong. As the anticyclone moves towards the western Bight an offshore east-southeast flow becomes established over the western coast of Western Australia. A trough forms off the coast, aided by the leeside effect on the stream flowing off the Western Australian plateau most of which is between 300 m and 600 m above sea level. With a further movement east of the anticyclone, the heat trough begins to deepen with the onset of warm advection from the interior of the continent. Finally a further deepening and movement inland of the trough is normally associated with the continued progression of the anticyclone into the southeastern Australian region. The approach of a well marked frontal system and its associated upper trough towards the southwestern Bight is also a major component of the sequence. With the breakdown of the upper-level anticyclonic easterlies over the west coast, and the onset of a northwesterly flow ahead of the upper trough, upper-level divergence over the region helps to deepen the heat trough.

The above sequence is illustrated by the surface and upper-level synoptic charts of Figs 3 and 4, which show the establishment and subsequent deepening of the Australian west coast trough during the period 4 to 9 February 1974. In the first day or so as the easterlies become established, the trough begins to develop just off the coast, and it has deepened significantly by the 8th owing to the enhanced thermal advection from the continent, and the effects of the front and associated upper trough approaching from the southwest. When the front reaches the southwestern tip of Western Australia on the 9th, the trough has moved inland, and deepened in response to the associated sharp upper trough near the west coast.

The pattern described above and exemplified by the period 4 to 9 February 1974 in which large well-defined steadily moving systems are involved, should be considered to be of high predictability as most of the changes in position and amplitude of the trough are gradual ones.
An example of non-classical west coast trough development

In contrast with the classical trough situation are the non-classical or unusual developments frequently associated with the Australian west coast trough in summer. There are many types of irregular behaviour, usually being related to unusually rapid development or movement; location relative to the coast; interaction with other synoptic patterns such as heat lows, tropical cyclones or mid-latitude systems; or the sudden genesis of other circulations such as small low pressure systems within the trough.

The last-mentioned type of irregular behaviour can be very difficult to predict, and it can also be hard to forecast subsequent development. Moreover, the screen temperatures experienced along the west coast depend critically upon the latitudinal positioning of the small low pressure system. If, for example, it is north of Geraldton (location specified in Fig. 1), the southern west coast will be less likely to receive a sea-breeze and therefore lower temperatures than if the low is south of Geraldton.

Description of the numerical model

The model used in these experiments is an improved version of the operational numerical model employed by the Australian Bureau of Meteorology for its twice-daily 24-hour forecasts (McGregor et al. 1978). The operational and improved models are shown in comparison in Table 1. There are four main areas of difference between the models. Firstly, the improved model has increased horizontal and vertical resolution. The horizontal grid spacing is 125 km compared with 250 km for the operational model, and there are ten levels in the vertical compared with six for the operational model. Secondly, the improved model possesses a surface heat balance scheme in which surface temperature is predicted by algebraically summing the contributions from short and long wave radiation, sensible heat flux, latent heat flux and ground flux at the surface. Vertical heat exchanges between the surface and the model atmosphere through the boundary layer can then be calculated. Details of the heat balance scheme are given by Leslie (1980) and need not be repeated here. The surface heating scheme takes into account the intense radiational heating of the Australian continent in summer, unlike the operational model which has no radiation scheme and therefore no associated diurnal cycle. Thirdly, it is well known that orography plays a role in deflecting wind flow and realistic orography should therefore be provided. The orography present in the operational model is highly smoothed and is replaced in the improved model by the much more detailed orography available on the one degree resolution data set prepared by the National Centre for Atmospheric Research. Fourthly, the incorporation of a nested lateral boundary condition scheme, in which boundary values for the limited area model are obtained from the hemispheric spectral model (Leslie et al. 1981), reduces prediction errors for systems located near, or about to enter, the southwest corner of the Australian region domain. The nesting procedure is now a part of the operational forecast model but was only introduced in April 1981 and has not yet been operational in any summer situations. The combination of nesting and the other three improvements collectively enhance the prediction of movement and development of other systems in the vicinity of the Australia west coast trough, in both the lower and upper troposphere.

The improved model, as described above, has been extensively tested and reported on elsewhere (Leslie 1980; Leslie et al. 1981) but cannot be implemented operationally within the Australian Bureau of Meteorology’s current computing resources. However, the improved model would run comfortably in the Bureau of Meteorology’s upgraded system, expected sometime in 1982.

Table 1. A comparison of the characteristics of the operational and improved ARPE models.

<table>
<thead>
<tr>
<th>Model characteristic</th>
<th>Operational model</th>
<th>Improved model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal resolution</td>
<td>250 km</td>
<td>125 km</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>6 levels</td>
<td>10 levels</td>
</tr>
<tr>
<td>Time differencing</td>
<td>Leapfrog semi-implicit with time step 36 minutes</td>
<td>Same but with timestep 18 minutes</td>
</tr>
<tr>
<td>Surface heat budget/</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>diurnal cycle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orography</td>
<td>Highly smoothed</td>
<td>Realistic</td>
</tr>
<tr>
<td>Lateral boundaries</td>
<td>Nested but not before April 1981</td>
<td>Nested</td>
</tr>
</tbody>
</table>
Results of predictability experiments

The improved forecast model was applied to 30 situations, of which fifteen were chosen each from the summer months of 1979-1980 and 1980-1981 respectively. Approximately half of these were regarded as being of inherent high predictability (gradual change over 24 hours) and the other half of inherent low predictability (unusual or irregular change).

It is accepted that the selection of situations based on apparent level of predictability is somewhat subjective, particularly in the more marginal cases. However, it should be stressed that the classification is not a typology, but largely a device for ensuring that a reasonable number of both straightforward and more interesting examples are selected for experimentation. Moreover, an alternative does not readily suggest itself. Checking persistence $S_i$ skill scores also does not add confidence to the choice of situations. Intuitively one might expect persistence scores to be larger for the low predictability case than for the high predictability cases. However, this is not borne out by the examples chosen because, for example, a high predictability rating often depends on regular change rather than little change in the forecast period.

The situations were therefore chosen and grouped as either of high or low predictability on the basis of assessment by one of the authors (TC LS) who has had extensive experience in routine forecasting of the west coast trough at the Perth regional office. Other experienced meteorologists were consulted and broadly confirmed the groupings.

In the discussion of results presented below, the overall results of the predictability experiments will first be summarised. Then four individual situations will be looked at in detail, two of high and two of low predictability.

Summary of results from all experiments

As mentioned at the beginning of this section, fifteen situations were chosen from each of the past two summers. The operational numerical ARPE and manual prognoses were assessed subjectively and $S_i$ skill scores calculated for a subset of the Australian region analysis and forecast domain located over the southwest of the chart (see Fig. 5). The results of these assessments are summarised in Table 2, in which the three forecast techniques are directly compared on their performance for both high and low apparent predictability. The improved ARPE model exhibits a large increase in forecast skill on both objective and subjective assessment. The skill scores for the manual and operational ARPE are fairly similar, but the improved ARPE has lowered the $S_i$ scores by four to five points which is a considerable reduction. Subjectively, the improved ARPE was rated as giving the best forecast guidance on more than two-thirds of the situations,

Table 2. $S_i$ skill scores and subject assessment ratings for fifteen high predictability and fifteen low predictability situations for the manual, operational ARPE and improved ARPE forecasts.

<table>
<thead>
<tr>
<th>Forecast technique</th>
<th>Number of situations</th>
<th>Predictability category</th>
<th>$S_i$ score MSL</th>
<th>Subjective superiority (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational</td>
<td>Manual</td>
<td>15</td>
<td>High</td>
<td>49</td>
</tr>
<tr>
<td>Improved</td>
<td>ARPE</td>
<td>15</td>
<td>High</td>
<td>47</td>
</tr>
<tr>
<td>Improved</td>
<td>ARPE</td>
<td>15</td>
<td>High</td>
<td>43</td>
</tr>
<tr>
<td>Operational</td>
<td>Manual</td>
<td>15</td>
<td>Low</td>
<td>51</td>
</tr>
<tr>
<td>Improved</td>
<td>ARPE</td>
<td>15</td>
<td>Low</td>
<td>49</td>
</tr>
<tr>
<td>Improved</td>
<td>ARPE</td>
<td>15</td>
<td>Low</td>
<td>44</td>
</tr>
</tbody>
</table>
with the operational ARPE and manual forecasts being regarded as nearly equal. Moreover, for the remaining one-third of the situations the improved ARPE model was never rated more than marginally worse than the operational ARPE and manual forecasts. The supremacy of the improved ARPE model is further underlined by the fact that it was never rated worse than fair, whereas the operational ARPE and manual forecasts were rated as poor or very poor on eleven and twelve occasions respectively out of the total of 30 situations.

The superior performance of the improved ARPE model is a direct consequence of its ability to represent more adequately the ingredients of the heat trough, namely, intense surface heating, location and movement of surrounding synoptic systems, and orography; and the interaction of these ingredients. This ability is best illustrated by looking at some forecasts in detail, as will be done immediately below.

**Case studies**

Four situations have been chosen for detailed examination, two of which are rated as being of high predictability, that is, showing only regular change during the forecast period, and two of low predictability.

**Situation 1**: 00 GMT 10 January 1981. This is a situation regarded as difficult (low predictability). In the 24-hour period 00 GMT 10 January to 00 GMT 11 January the heat trough deepened dramatically over southwest Western Australia and the small low moved southwards from east of Exmouth Gulf to just offshore from Cape Naturaliste, as shown in Figs 6(a) and (b). The manual forecast (Fig. 6(c)) deepened the trough only slightly and performed poorly being assessed subjectively as very poor and rating an $S_3$ skill score of 59 (Table 3). The operational ARPE model performed considerably better (Fig. 6(d)) but still only moved the small low to just west of Geraldton, and was rated subjectively as fair and objectively with an $S_3$ skill score of 48. The improved ARPE model moved the small low to a position just off the coast south of Perth, thereby giving the best forecast guidance of all three prediction techniques (Fig. 6(e)). It was assessed subjectively as providing good forecast guidance and the computed $S_3$ score was 44 (Table 3).

The improved ARPE model was superior mainly because it moved the large anticyclone in the Bight rapidly towards the southeast to just west of Bass Strait, whereas the operational and numerical models moved the anticyclone on a more eastwards path. The more accurate track is almost certainly due to the greater land/sea thermal differential developed by the improved ARPE model.
Table 3. \(S_1\) scores and subjective ratings of the four case studies discussed.

<table>
<thead>
<tr>
<th>Situation base time</th>
<th>(S_1) score</th>
<th>Subjective rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manual ARPE</td>
<td>Operational ARPE</td>
</tr>
<tr>
<td>1.00 GMT 10 January 1981</td>
<td>59</td>
<td>57</td>
</tr>
<tr>
<td>2.00 GMT 11 March 1981</td>
<td>55</td>
<td>53</td>
</tr>
<tr>
<td>3.00 GMT 14 February 1981</td>
<td>43</td>
<td>42</td>
</tr>
<tr>
<td>4.00 GMT 23 March 1981</td>
<td>53</td>
<td>52</td>
</tr>
</tbody>
</table>

**Situation 2**: 00 GMT 11 March 1981. In some ways this situation is the opposite of situation 1 in that its difficulty (low predictability) lies in its rapid weakening of the west coast trough, as shown in Figs 7(a) and (b). None of the forecast techniques adequately simulated this weakening although the improved ARPE model was closest by a considerable margin, as can be seen by the location of the 1016 and 1020 mb contours along the west coast (Fig. 7(e)). The manual prediction actually strengthened the trough slightly (Fig. 7(c)). The relative skills of the three prognoses are shown in Table 3. The manual forecast was subjectively regarded poor \(S_1 = 55\), the operational ARPE as very poor \(S_1 = 53\) and the improved ARPE as fair \(S_1 = 48\).

The main reason for the poor quality of the operational forecasts was their failure to predict accurately the strong pressure rises to the rear of the cold front which moved into the central Bight.

**Situation 3**: 00 GMT 14 February 1981. This situation was rated as not difficult (high predictability) because even allowing for a sudden deepening of the heat low in the De Grey region the pattern of evolution over the west coast region was regular, with a large anticyclone ridging from the Indian Ocean into the Bight (Figs 8(a) and (b)). All three forecasts were rated good and the \(S_1\) scores for each were fairly similar, the manual, operational ARPE and improved ARPE scores being 43, 42 and 41 respectively (Table 3).

There was, however, an interesting aspect of situation 3 that merited further attention. The maximum temperature forecast for Perth issued by the Perth RFC was 24°C whereas the actual maximum was 31°C. An error equal to or greater than 6°C is regarded as a major forecast error. The Perth centre had expected an early switch of wind away from the east but this did not occur. The dry bulb screen temperatures are plotted in Fig. 9 as a function of local time. The improved ARPE model carries a prediction equation for surface and one metre (screen) temperature. It is noteworthy that the model predicted temperature trace shown in Fig. 9 predicts a maximum of 29.5°C at 1630, which accords well with the observed maximum. It should be stressed at this point that no general claims are being made concerning the accuracy of forecast maximum temperatures from the numerical model. To do so would require a separate study focusing on maximum temperature forecast failure situations.

**Situation 4**: 00 GMT 23 March 1981. This situation is another high predictability case in which a frontal system to the south of the head of the Bight pushes through rapidly to the eastern Bight and is accompanied by strong ridging in the Bight (Figs 10(a) and (b)). Cooler air advected into the west coast region by the anticyclone weakens the trough considerably.

Perhaps surprisingly, both the manual and the operational ARPE forecasts performed poorly on this situation, neither of them predicting sufficiently rapid ridging in the Bight (Figs 10(c) and (d)). The respective \(S_1\) skill scores were 53 and 52. The improved ARPE model, on the other hand, produced a good forecast with an \(S_1\) score of 45 (Fig. 10(e)) largely because it did capture the rapid ridging. In this particular case it appears that the nested boundary conditions played a major role in the increased forecast skill as it allowed eastwards movement of the frontal system on the southern boundary and concomitant ridging to the northeast, unlike the quasi-constant operational ARPE model boundary conditions which prevented such evolution in this situation.

**Concluding remarks**

Improvements made to the Bureau of Meteorology's operational Australian region model have resulted in more accurate forecasts of the position and amplitude of the Australian west coast trough during the summer months. The degree of increased skill obtained in these experiments would be expected to have a significant impact on routine forecasting for southwestern Australia if the improvements were implemented operationally.

Further work of a more detailed nature is
Fig. 7. As in Fig. 6, for base date 00 GMT 11 March 1981.

Fig. 8. As in Fig. 6, for base date 00 GMT 14 February 1981.
Fig. 9. Model predicted screen temperatures and thermograph readings for period 0900 to 2100 hours local time Perth RFC.

\[ \text{Temperature, } ^\circ\text{C} \]

- Thermograph Reading
- Predicted

0900 1100 1300 1500 1700 1900 2100

Local Time, Hours

Fig. 10. As in Fig. 6, for base date 00 GMT 23 March 1981.

Acknowldgments

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References


