

Analysis of screen-level temperature and dew-point in the Australian region

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An operational analysis system for screen-level temperature and dew-point has been developed for the Australian region. Amongst its many intended uses are (i) to improve temperature profile retrievals from the operational TOVS (TIROS Operational Vertical Sounder) system, (ii) to provide initial surface conditions for the regional forecast model and (iii) to assist with regional forecasting problems (e.g. fire weather). Analyses of mean sea level pressure, screen-level temperature and dew-point are performed every three hours (2300 UTC, 0200 UTC, etc.) on a $1^\circ \times 1^\circ$ latitude-longitude grid over the domain 45°S to 10°S , 110°E to 155°E .

Examination of the analyses indicates that they are consistent with the low-level flow field, and provide a realistic representation of the observations. They are shown to delineate sharp discontinuities in the temperature and moisture fields, and to provide superior initial surface conditions for the regional forecast model than are currently available.

Introduction

A univariate optimum interpolation analysis scheme for surface screen temperature and dew-point has been developed for the Australian region. The analyses can be used in many aspects of the Bureau of Meteorology's updated analysis and prognosis system. The primary motivation was to improve the method for obtaining temperature profiles from the TOVS system (Kelly et al. 1983). Over land the retrieved temperature profiles in the lower layers of the atmosphere are uncertain because of contamination of the atmospheric radiance by radiation from the earth's surface. A knowledge of the surface temperature will allow this component of the radiance to be calculated and taken into account.

Other motivating factors in the development of the surface system were (i) to improve the specification of initial surface conditions for the new Australian Region Primitive Equations model (Leslie et al. 1985), and (ii) to provide some additional aids for operational forecasting and diagnostic research, e.g., in fire weather forecasting, and in monitoring the position of the north Australian 'dry-line' moisture discontinuity — the line separating moist tropical air from dry continental air.

The univariate optimum interpolation scheme used here was adapted from the tropical analysis system of Davidson and McAvaney (1981), hereafter referred to as DM. The advantages of using this technique, and the details and formalism of the scheme are discussed in DM and the references contained therein.

Details of the scheme

Data handling

The observational base is the surface synoptic data and ship data of the Australian region. The observational data (mean sea level pressure (MSLP), screen temperature (T) and dew-point (T_d)) are accepted within one hour of analysis time. Because of the lack of observations over the ocean and the need for analysis stability, monthly, long-term-mean sea surface temperatures (SSTs) are inserted as bogus observations (PAOBS) at specified latitude, longitude points at 5 degree intervals. For low-level moisture over the ocean a value of $T_d = (\text{SST}-3)\text{K}$ is used. A method for collecting SST observations over a two-week period is currently being developed. Incorporation of this data into the system will alleviate the need for bogusing.

Observations are rejected if they are markedly different from the first guess field, or from their neighbours (the buddy checking method discussed in DM).

The data search and selection are basically as described in DM. An important difference, however, is that in this system no ship or SST PAOBS are used to analyse land grid-points and no land observations are used to analyse sea grid-points. This prevents the severe damping of the diurnal temperature variation over the land by the influence of the steady sea temperature.

Sigma (σ) surface analysis

The analysis is performed on a topography-following sigma (σ) surface, where $\delta = p/p^*$, p^* is pressure at the surface, and p is the pressure at some vertical point above the surface. The analysis

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of temperature and dew-point is done at $\sigma = 0.999$. To determine p^* we require the altitude of the point above MSL and some means of transforming from MSLP to p^* . To determine the altitude at each point of interest we interpolate from a $6' \times 6'$ topography data set over the Australian continent supplied by the Bureau of Mineral Resources. p^* is then obtained from this altitude and the MSLP value using a transformation discussed by Colquhoun (1965).

First guess fields

The first guess MSLP field is obtained from interpolation to analysis time of the relevant Australian region analyses and prognoses. For the initial analysis in a sequence the archived 1000 mb temperature analysis of the Australian region is used for the temperature first guess, and for dew-point, the temperature analysis minus 10 degrees is used. Once the system is running, the previous 3-hour analysis is used as first guess. A climatological diurnal correction for temperature is also available to improve the first guess over data sparse areas and at those times when the observing network is limited (e.g. 1700 UTC). Eventually the surface system will be part of an assimilation system in which the first guess will be provided by a numerical prediction model, which incorporates a parameterisation of the diurnal cycle, and a surface temperature and moisture prediction scheme.

Correlation functions

The three-dimensional guess field error correlation function is similar to the one discussed in DM and takes the form

$$\mu_{ij}(x_i, x_j, y_i, y_j, p_i, p_j) = \psi_{ij}(x_i, x_j, y_i, y_j) \sigma_{ij}(p_i, p_j)$$

where ψ_{ij} is the horizontal function and σ_{ij} the vertical function. The horizontal function is

$$\psi_{ij} = \exp(-k_H S_{ij}^2)$$

where

$$S_{ij}^2 = (x_i - x_j)^2 + (y_i - y_j)^2$$

and

$$k_H = 3.24 \times 10^{-6} \text{ km}^{-2}$$

Since the relevant statistics of guess field error were not known, k_H was determined empirically. The value given here ensures that even over data sparse areas, the influence of the observations is spread far enough to dominate the first guess field. The k_H value corresponds to an e-folding length of approximately 550 kms.

The vertical function is

$$\sigma_{ij} = \frac{1}{1 + 5 [\ln(p_i/p_j)]^2}$$

where p_i and p_j are p^* at the surface locations i and j respectively. The use of this function ensures that an

observation at an altitude different from the grid-point altitude will have less weight than one at the same height.

Assigned RMS errors

The first guess standard deviations or RMS error for temperature and dew-point are

$$\sigma_e(T) = 3.0^\circ\text{C}, \text{ and } \sigma_e(T_d) = 5.0^\circ\text{C}.$$

The assigned observation RMS errors for SYNOPTIC stations are

$$\sigma_e(T) = 0.75^\circ\text{C}, \text{ and } \sigma_e(T_d) = 1.25^\circ\text{C}.$$

and for SHIPS are

$$\sigma_e(T) = 1.0^\circ\text{C}, \text{ and } \sigma_e(T_d) = 2.0^\circ\text{C}.$$

These values for first guess and observation errors, represent realistic values and ensure that the observations always dominate the first guess.

Analysis output

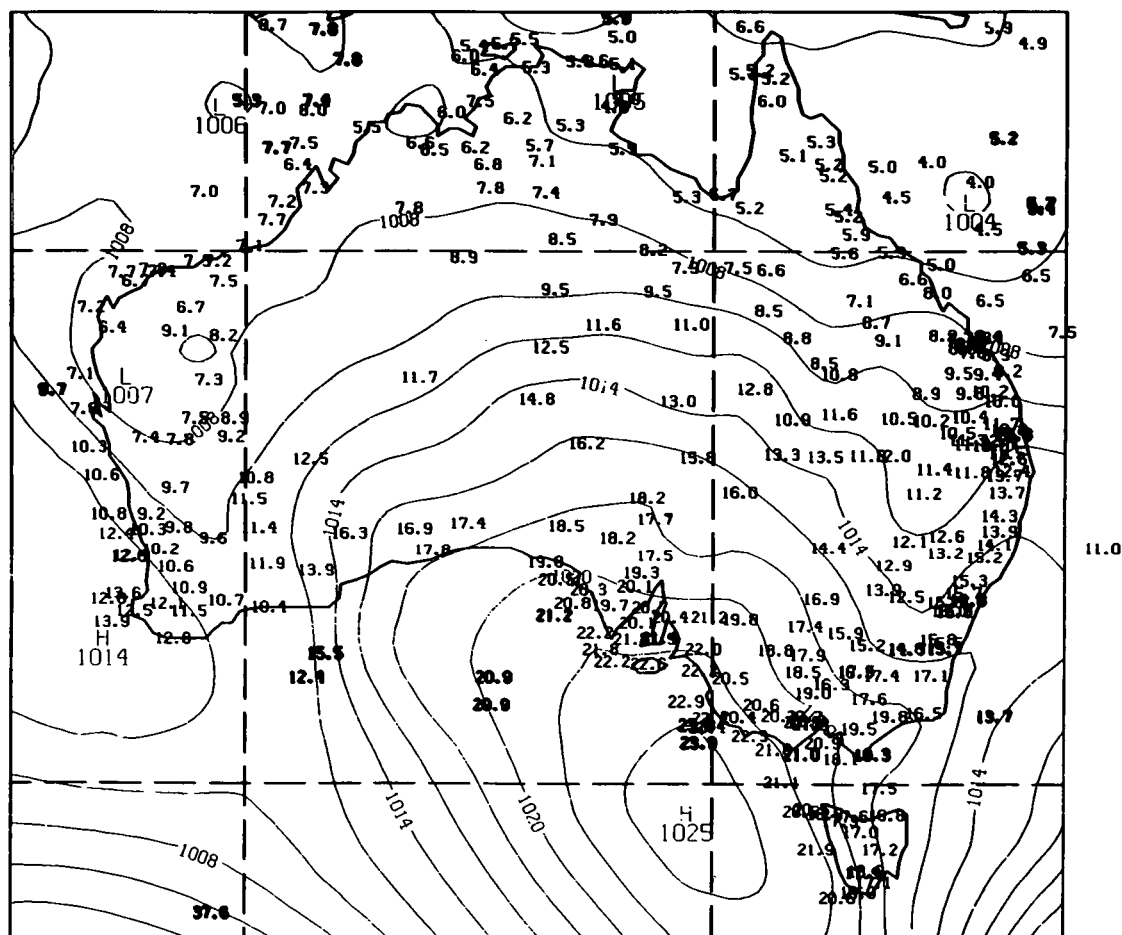
Typical examples of MSLP, surface temperature and surface dew-point analyses are shown in Figs 1(a), (b) and (c). The analysis time is 2300 UTC which corresponds to 9 am in eastern Australia and 6 am in Western Australia.

The MSLP analysis shows a general easterly trade wind regime over most of Australia. The subtropical ridge is interrupted over southwestern Australia by the Western Australian heat trough and a cold frontal system in the mid-latitude westerlies. The monsoon trough is just discernible around the northwest Australian coast, then up through Darwin, the Gulf of Carpentaria and Cape York Peninsula.

Inspection of the temperature and dew-point fields indicates that the analyses are consistent with the MSLP pattern, and the observations generally well paid. RMS observation minus analysis differences for a large number of analyses are 1.3°C for temperature and 2.4°C for dew-point. The sharp temperature and moisture discontinuities associated with the trough over Western Australia are extremely well represented. There is a clear delineation of the (eastward) extent of the warm air to the east of the trough. The temperature minimum over the Great Dividing Range through southeastern and eastern Australia is evident, but does not appear to be distinct enough due to the lack of observations over the high country. Finally the dry-line moisture discontinuity over northern Australia, defining the boundary between the dry trade wind air and the moist tropical air, is well defined by the dew-point analysis.

Some minor deficiencies evident in the analyses are almost entirely due to our lack of experience with mesoscale analysis of variables that are only

Fig. 1(a) Mean sea level pressure analysis for 2300 UTC 31 January 1984. The contour interval is 2 hPa. The location of each observation is to the right of the printed value. The heavy plots are ship observations.



TROP MSLP 840131 2300

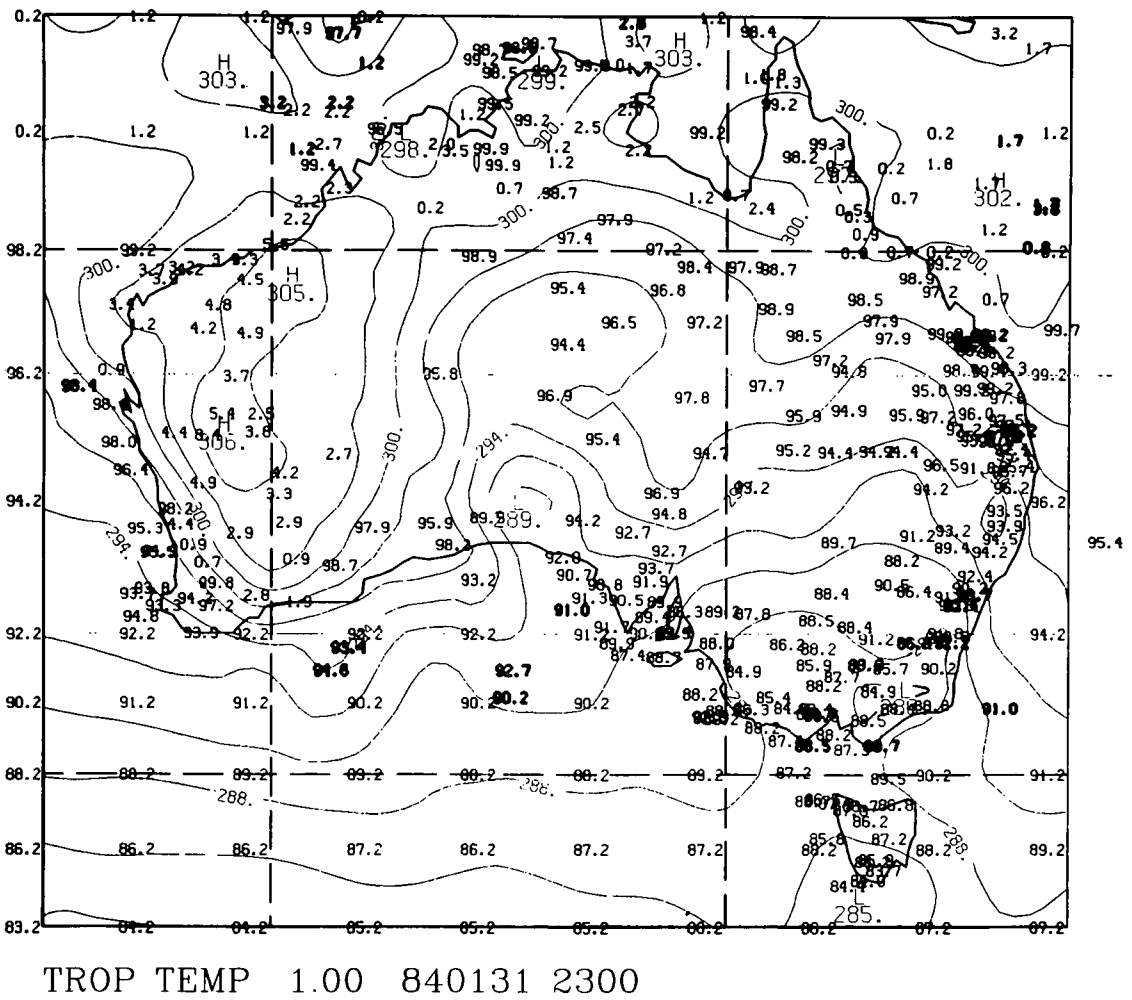
representative of local conditions. Fortunately the optimum interpolation system provides the flexibility for further refinements as our knowledge and experience grows.

The correlation function used is a scalar function of the distance s_{ij} between the points i and j . No directional dependence is included. This isotropic assumption is probably satisfactory for grid-points well inland or far out over the ocean. However near the coast where land-sea differences can sometimes result in large gradients of both temperature and moisture this may not be the case. In this non-isotropic situation a non-isotropic correlation function dependent on topography and coastal geometry would probably increase the analysis

accuracy. Hessler (1984) in experiments with statistical analysis of surface temperature fields in the Baltic Sea region found that the interpolation error was significantly decreased if anisotropic effects on coastal zones are taken into account.

By visual examination and by comparing the numerically produced contours with hand analyses, we come to the conclusion that over data dense areas such as southeast Australia the numerical analysis is too smooth. The reason for this is that the scale length or $1/e$ length of the horizontal correlation function is 5 latitude degrees. This length was chosen so that grid-points in the data sparse areas of central Australia would all be influenced by observations. However, this length

Fig. 1(b) As in Fig. 1(a), but for surface temperature. Units are K.



scale smooths out some of the smaller scale variations of surface temperature and dew-point. A possible solution to this would be to use a correlation length scale dependent locally on data density. This flexibility is permitted by the optimum interpolation technique.

Close inspection of the analyses and observations reveals that some incorrect observations may not have been trapped by the checking system. This emphasises the difficulty in separating signal from noise for mesoscale variables at very small scales, and particularly for isolated observations. Further refinements to the observation checking system and a manual intervention facility – which is currently

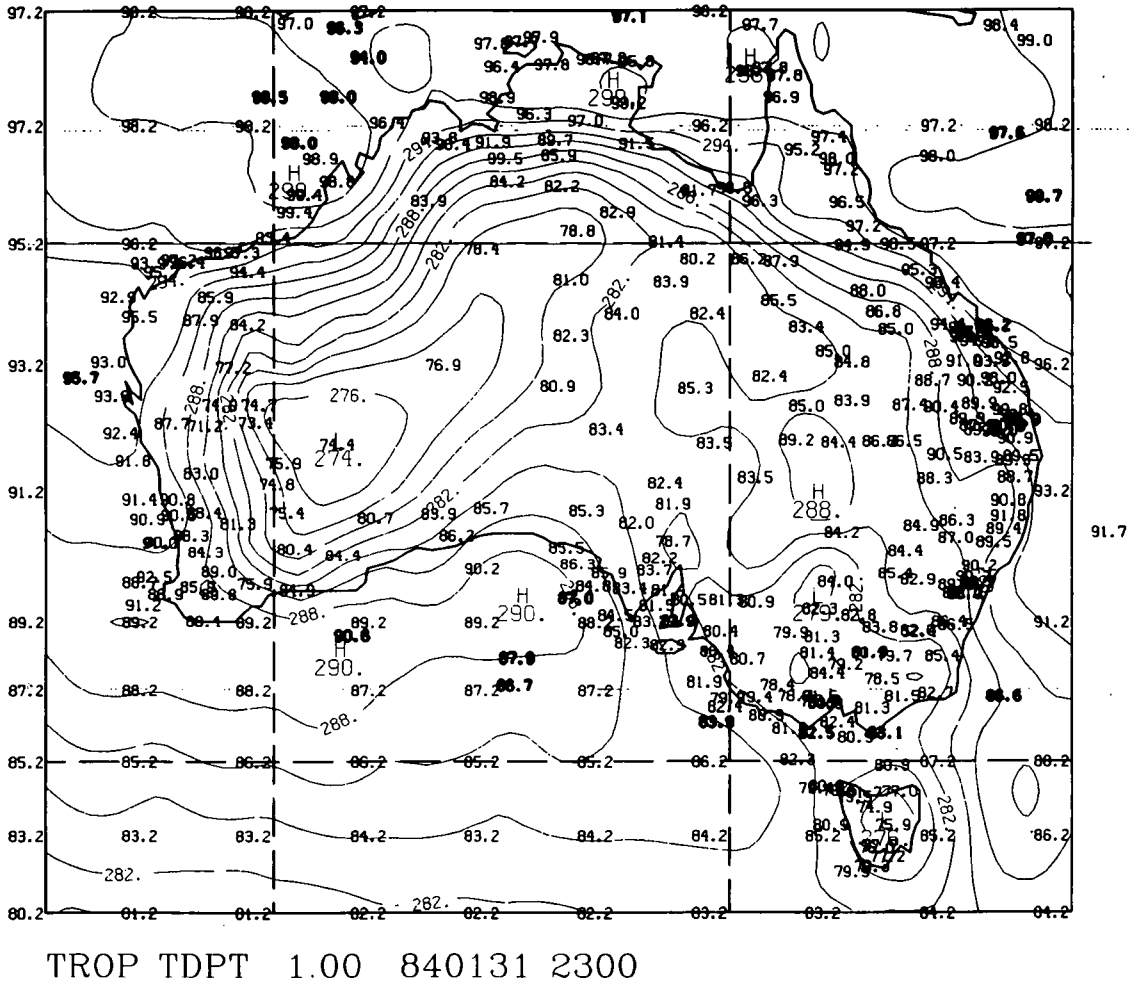
being developed – will help to alleviate some of these difficulties.

Finally we wish to emphasise that fine tuning and further sophistications to cope with the deficiencies described above will not drastically alter the quality of the analyses. In the configuration described here the scheme is extremely well-behaved and has produced excellent quality results over a wide range of meteorological situations.

Applications

In a short term forecasting environment, the surface analysis system has many obvious applications: e.g. in fire weather forecasting, in defining and tracking

Fig. 1(c) As in Fig. 1(a), but for surface dew-point. Units are K.



warm and cold air boundaries, and in tracking moist and dry air masses. Moreover the impact of surface analyses on satellite retrieved temperature profiles has been adequately demonstrated elsewhere (Le Marshall 1985) and will not be considered here. At low levels RMS retrieved temperature errors decrease by approximately 2°C with the use of a surface analysis.

One of the important functions of the system to operational forecasting will be to provide initial conditions of surface temperature and dew-point for the Australian Region Primitive Equations model. Leslie et al. (1985) have indicated that it may be possible to provide forecast guidance on the diurnal

variation of screen level temperature at specific locations. This obviously requires initial values.

Before the surface analysis system became available the initial surface temperature field for the forecast model was obtained, over the whole domain, from the lowest model sigma level (see Leslie et al. 1985). This in turn was based on analyses of radiosonde data and not surface synoptic data. When the surface system became available, the initial surface temperature field was specified from long-term climatological SSTs over the ocean, and from the surface analyses over land. An example of the surface temperature field derived in both ways is shown in Figs 2(a) and (b). Because of the different

Fig. 2(a) Initial surface temperature field available to the Australian Region Primitive Equations model for 2300 UTC 20 June 1984, without the advantage of the surface analysis. Units are K.

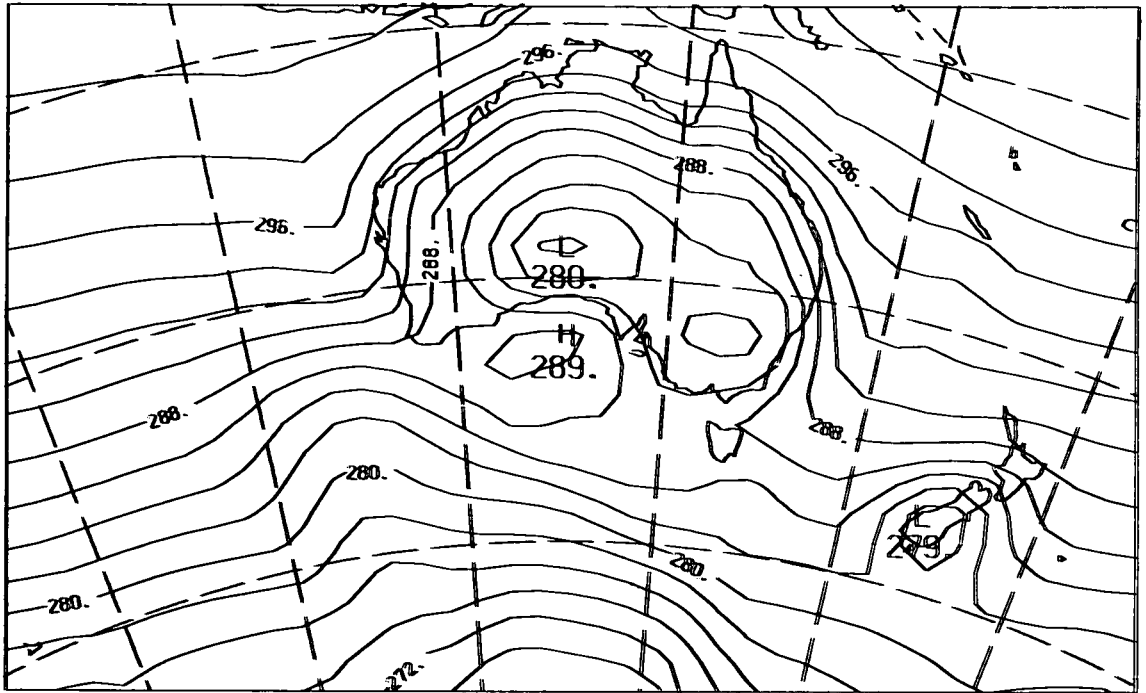
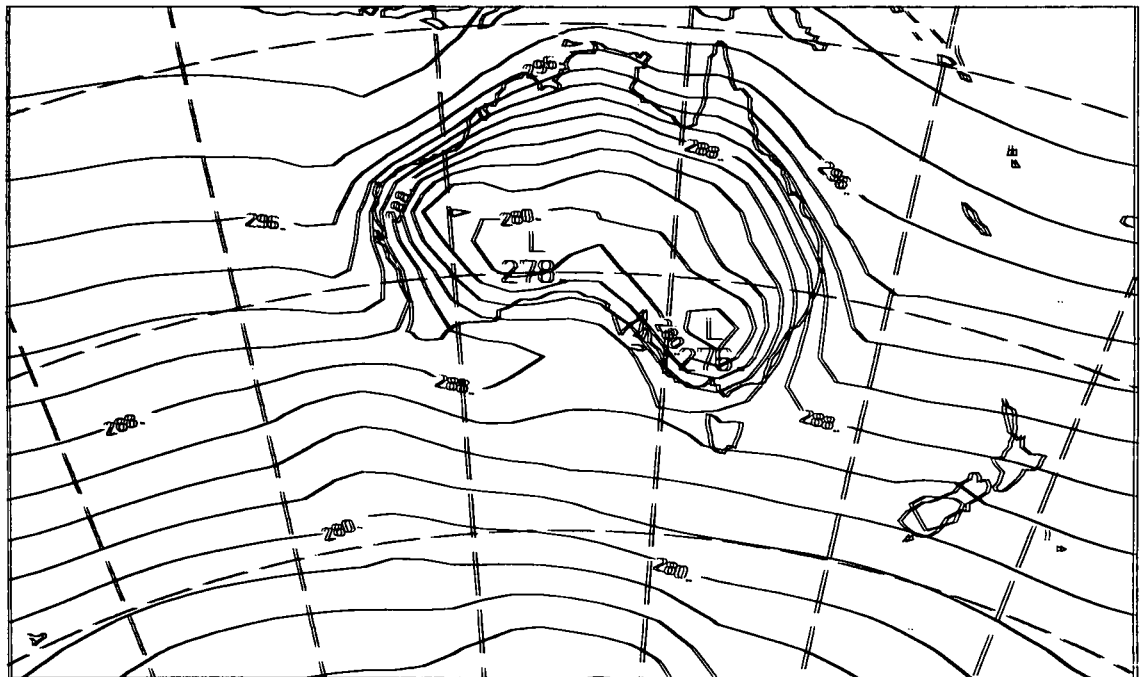


Fig. 2(b) As in Fig. 2(a) but with the surface analysis of temperature included.



methods of obtaining these initial fields, differences are evident over the ocean. However, this does not account for the substantial differences over parts of the land area. Temperature differences through the region from central Western Australia to Victoria range up to 6°C, with the new system, (Fig. 2(b)) providing a far superior representation of the observed temperatures. Differences, even more dramatic than those in Fig. 2, are also evident in the near surface moisture fields (not shown). Here as well, we suspect that the closer representation of the observations will have a beneficial effect on numerical forecasts, since the radiative, convective and rain processes within the model are partly dependent on low level moisture.

Finally we wish to emphasise that the improvements in the analysis noted here are due primarily to the utilisation of the surface synoptic data and not to differences in analysis techniques.

Summary

An operational analysis system for surface temperature and dew-point has been developed for the Australian region. Amongst its many uses are (i) to improve temperature profile retrievals from the operational TOVS system, (ii) to provide initial surface conditions for the regional forecast model, and (iii) to assist with regional forecasting problems (e.g. fire weather). Analyses of mean sea level pressure, surface temperature and dew-point are performed every three hours (2300 UTC, 0200 UTC, etc.) on a 1° x 1° latitude-longitude grid over the domain 45°S to 10°S, 110°E to 155°E. The analyses are consistent with the low level wind field, and provide a realistic representation of the observations. They have been shown to delineate sharp discontinuities in the temperature and moisture fields, and to provide superior initial surface conditions than are currently available for the regional forecast model. An anonymous reviewer has also suggested that the system has potential for the objective analysis of a wide range

of climatological data, collected over the Australian continent. We believe that the scheme could be easily adapted to cope with this interesting application.

The system is well-behaved, and has produced excellent quality results in a large number of situations (not shown here). Minor improvements in the system will result from (i) better use of climatological data, particularly over high topography, (ii) improved specification of the correlation functions for mesoscale variables, and (iii) improved first guess fields, perhaps from numerical forecast models. The flexibility of the analysis system will allow these improvements to be incorporated easily as our knowledge and experience with mesoscale analysis grows. We also hope to incorporate satellite retrieved skin temperatures over cloud-free areas. This, together with analyses of screen level temperature, dew-point and anemometer-level wind will allow more accurate estimates of surface fluxes to be obtained.

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