

# AN OPERATIONAL EVALUATION OF A NUMERICAL ANALYSIS-PROGNOSIS SYSTEM FOR THE SOUTHERN HEMISPHERE

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with

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## ABSTRACT

A general description is given of a numerical analysis-prognosis system which has been designed specifically for operational use over the southern hemisphere. In addition to comment regarding possible future development prospects, the results of a recent operational evaluation of the system are presented. The operational results are generally creditable and invite acceptance of system potential.

## INTRODUCTION

The experiment reported in this paper represents the latest extension in a continuing research effort to extend the scope, accuracy and time scale of numerical weather prediction in the southern hemisphere. One of the focal points in this research is the further development and evaluation of a hemispheric numerical analysis-prognosis system which utilises a six level primitive equation model developed by Smagorinsky *et al* (1965) and subsequently restructured by Gauntlett and Hincksman (1971). Previous operational trials with this system have been concerned mainly with the evaluation of individual system components, whereas in the current experiment, interest has been directed more toward an assessment of overall system stability and performance in a continuous operating environment.

A further motivation for the experiment was the requirement for an operational evaluation of a "dynamic" initialisation scheme similar to that originally proposed by Nitta and Hovermale (1969). In recent non real-time comparisons with conventional "balanced" initialisation methods, Gauntlett (1971) has shown that this "dynamic" approach to initialisation can result in a useful enhancement in the quality of numerical forecasts obtained from the primitive equation model.

Finally, and perhaps most importantly the experiment provided a valuable training medium for operations specialists at the World Meteorological Centre (WMC), Melbourne to familiarize themselves with the "man-machine mix" processes which are an integral part of any operational numerical system. In the southern hemisphere in particular, the "man-machine mix" process assumes added significances due to the present heavy reliance placed on satellite cloud mosaics and the consequent requirement for adequate interpretative techniques.

## EXPERIMENT DESIGN

The hemispheric numerical system under consideration was run on a continuous operational basis by WMC, Melbourne from 6 June 1971 to 4 July 1971. The analysis-prognosis cycle was run on a 24-hour frequency. The typical real-time sequence of operational functions during an analysis-prognosis cycle is shown in Fig 1. Two aspects of the cycle require particular comment. Considerable time (approximately 9 hours) is required for the receipt of sufficient hemispheric data under existing communications facilities; due to limited computing resources, a further 3 hours are required to complete the analysis-prognosis cycle. As a result of these limitations it is currently impossible to prepare "operationally timely" 24 hour hemispheric forecasts with the model configurations utilised in the current experiment. Forecasts may however be extended beyond 24 hours by expending only an extra 2 hours for every additional 24 hours in forecast extent. The possibility of producing "operationally timely" extended range forecasts is therefore real and is the primary motivation in developing the present hemispheric system.

A more detailed description of the program processing sequence during a typical analysis-prognosis cycle is shown in Fig 2. During these experiments the WMC real time interactive control system designed by Maine (1969) was not used to facilitate manual interaction and program execution. Rather, individual programs including appropriate control information were activated using specially prepared "catalogued procedures", execution of a particular program being initiated by submission of a minimal number of cards to the computer.

## PRIMARY PROGRAM FUNCTIONS AND MODEL CONFIGURATIONS

### Data Collection

Data for the experiment was collected automatically using WMC's Telegraph Multiple Recorder (TMR). This device transfers character information from the communication lines to magnetic tape in a pre-specified format.

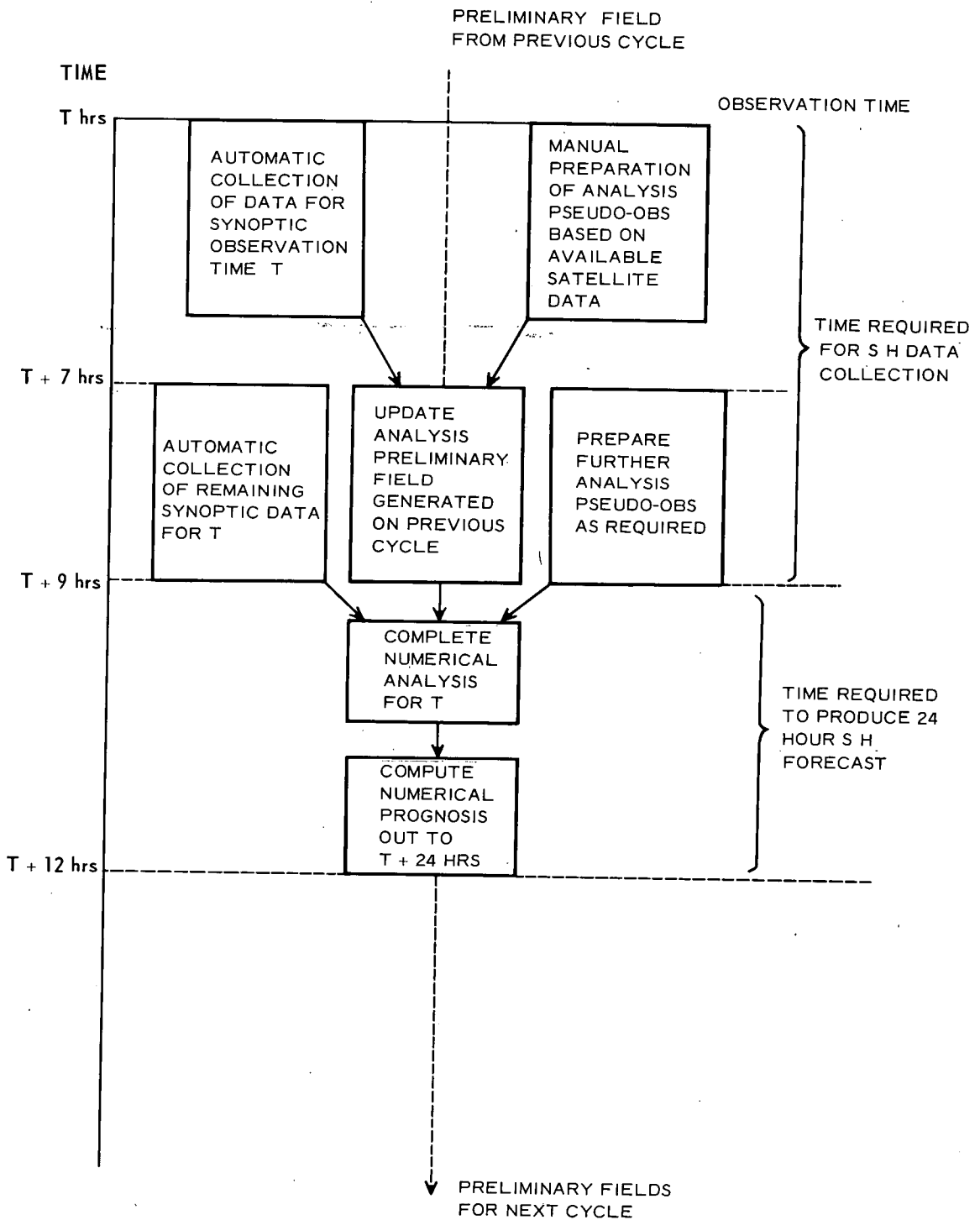


Fig 1 Real time sequence of operational functions during an analysis-prognosis cycle.

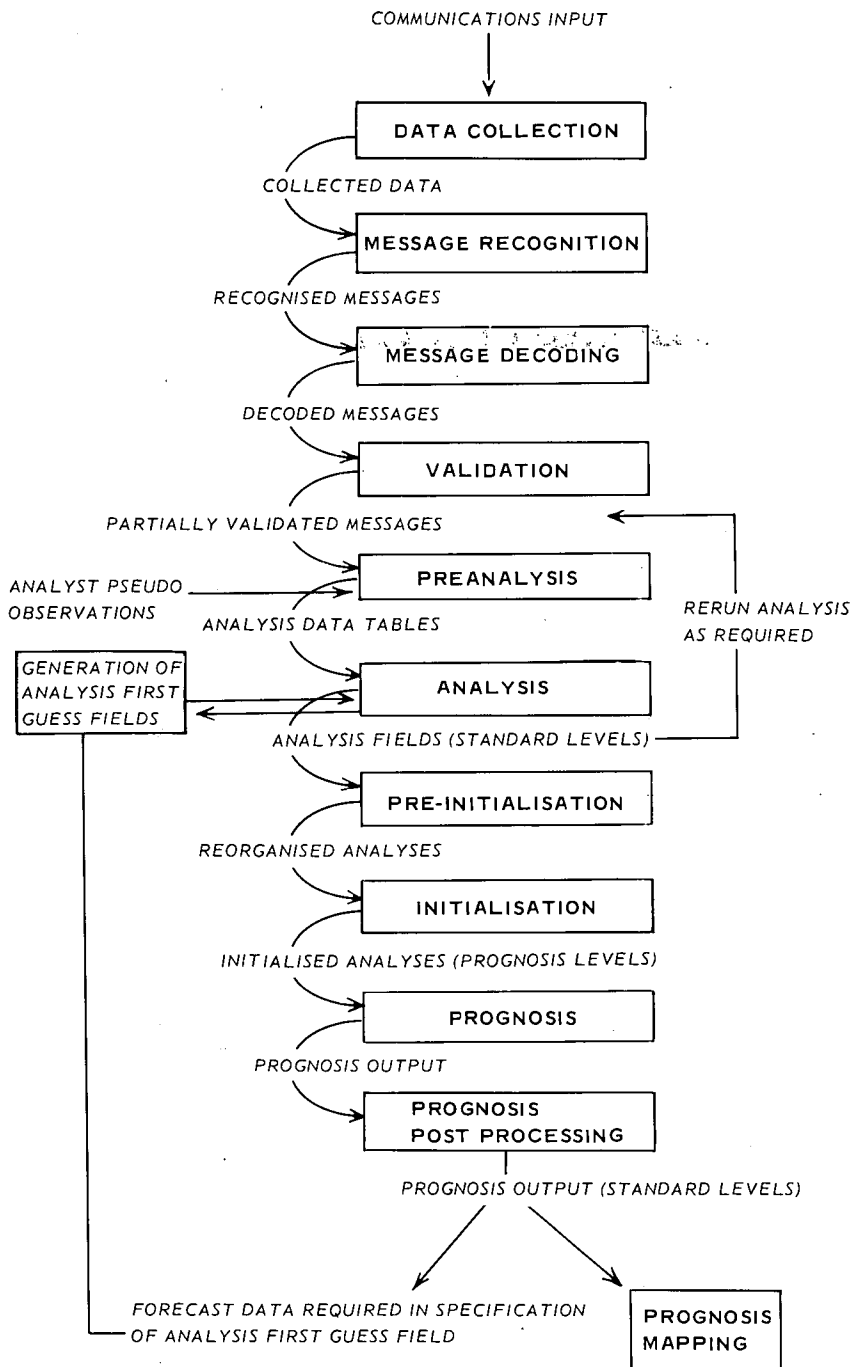


Fig 2 Information flow and program sequence during an analysis-prognosis cycle.

## Message recognition and decoding

From all the information received by the TMR, meteorological messages are recognized, decoded, and sorted by synoptic time, station identifier, and message type. Unresolved messages are indicated to enable manual correction.

## Validation

The decoded messages are subjected to a series of validity checks, including internal, spatial, temporal, hydrostatic, and vertical consistency. Suspect and corrected data are indicated.

## Preanalysis

Validated messages are reorganised according to chart level; at the same time, analyst-inserted pseudo-observations are accepted and added to the appropriate level. From pseudo-observations of 1000-500 mb thickness, "observations" of 500-300 mb, 300-200 mb, and 200-100 mb thickness may be generated automatically using climatological lapse rates, obtained from climatological grid data (Taljaard *et al* 1969).

## Analysis

The analysis model is based on the Australian regional model described by Maine (1966) and Maine and Seaman (1967). Apart from necessary changes in projection and grid resolution (a  $47 \times 47$  grid is used on a polar stereographic projection, with grid length 274 n mi (507 km) at standard latitude  $60^\circ$ ), the following additions and refinements have been made in order to meet particular requirements of the prognosis model, and also to maintain consistency between successive analysis and prognosis cycles.

- (i) Mixing ratio is analysed at each standard level up to 500 mb. The first guess field is the predicted mixing ratio, with a prescribed control by climatology. In this experiment, full prediction was used under "warm running" conditions *ie*, when predicted fields were used in preparing a first guess for the analysis. Climatology was used only at the initial "cold-start".
- (ii) Wind components are analysed at each standard level. These analyses are performed immediately after the geopotential analysis at the same level. In extra-tropical areas the first guess field is the sum of the gradient wind component obtained from the current geopotential analysis, and the "non-gradient" part of the predicted wind component. A predicted wind component is therefore unchanged by the analysis procedure in areas unaffected by observational data of any kind. In data areas however, geopotential information at the same level can influence the wind component guess field through the gradient wind relation. Also, mean sea level pressure or geopotential information at a lower level can influence upper wind guess fields through the differential procedure used to perform the geopotential analyses.

In the tropics, no pressure-wind relation is used in the analysis procedure, and first guess fields are obtained from predicted wind components with a specified control by climatology. In the experiment, full prediction was used under "warm running" conditions, and climatology only at the initial "cold start".

A weighted mean of the tropical and extra-tropical first guess fields is used in the transition zone between latitude  $15^{\circ}$  and  $25^{\circ}$ S.

- (iii) The first guess temperature at a particular level is obtained from the analysed thickness of the layer immediately below, and the predicted lapse rate. The predicted temperature is therefore unchanged by the analysis procedure in areas unaffected by data of any kind, thus ensuring consistency between analysis and prognosis. However, wind and wind-shear information can influence the temperature guess field through its effects on the lower thickness analysis.
- (iv) Consistency between analysis and prognoses at mean sea level and 1000 mb is ensured in the following way. When 1000 mb is a "real" pressure surface, the predicted mean temperature between MSL and 1000 mb is used to compute the 1000 mb geopotential guess field from the analysed MSL pressure. When 1000 mb is a fictitious surface, the mean temperature between MSL and 1000 mb implied by the pressure reduction procedure in the prognosis post-processing module is used.

### Pre-initialisation

In the pre-initialisation phase, analyses provided by the hemispheric analysis model on a  $47 \times 47$  grid are converted by interpolation to the  $61 \times 61$  grid of the prognosis model. Subsequently, further interpolation is used to transform these standard pressure surface analyses to the "sigma" surfaces of the prediction model. Finally, the surface pressure field is computed using analysed geopotential height and temperature information.

### Initialisation

The primary function of the initialisation program is to compute balanced wind and mass fields prior to the commencement of prognosis. This is necessary in order to minimise the occurrence, in the prediction model, of gravity-inertial oscillations induced by data errors and dynamic incompatibilities (with respect to the particular prognosis model) in the numerically analysed fields. The required dynamic balance in the initial fields is achieved using a "dynamic" initialisation method. In this scheme the actual prognostic model equations, modified only by the removal of irreversible terms are used in an iterative sense to produce the required dynamic adjustment. An actual iteration consists of forward and backward forecasts performed around the initial time utilising a modified version of the Euler-backward time differencing scheme.

### Prognosis

As mentioned previously the prediction model used in the experiments is that developed by Gauntlett and Hincksman. In brief, the general characteristics of the model are: primitive equation, six vertical levels using Phillip's sigma coordinates; hemispheric, N30 horizontal resolution, *ie*, there are thirty points between the pole and the equator on a polar stereographic projection; non-radiative, hydrological processes are incorporated including a parameterization for sub-grid scale convection and the effect of a smoothed orographic field; horizontal momentum changes due to internal viscosity are modelled according to the simple "del squared" formulation, whilst for the vertical, Prandtl mixing length theory is used. It should be noted that in these experiments the turbulent transfer of heat and moisture from the earth's surface was not included.

## Prognosis post processing

In the post processing phase, vertical interpolation is used to obtain predicted fields of wind, temperature and moisture for standard pressure surfaces from the corresponding sigma surface predictions of the forecast model. Finally, mean sea level pressure and the geopotential heights of standard pressure surfaces are computed from the predicted mass fields.

## DISTRIBUTION AND EXTENT OF SYNOPTIC DATA USED IN THE EXPERIMENTS

Although subject to considerable daily variation, the distribution and density of synoptic data shown in Fig 3 and 4 are fairly typical of those available during the test period. Due to practical contingencies, it should be noted that no data north of 15°S was utilised. Although far from optimal, it has been shown in this experiment that the data base can support a numerical system of some operational utility providing of course, adequate prognosis feedback is maintained, and also, maximum use is made of available cloud satellite information.

In the current experiments most available satellite data was of local APT origin and concentrated in the Australasian sector from 90°E to 180°E. Data for the rest of the hemisphere was subject to considerable variation in quality, extent and timeliness and was either in the form of neph-analyses received by radio-fax from San Francisco and/or gridded infrared mosaics received *via* the ATS 1 satellite.

With these limitations in view it was decided to limit manual intervention primarily to the Australasian sector. Over the remainder of the hemisphere manual intervention was invoked only when it was obvious from satellite data that the analysis-prognosis system had developed a gross variation from reality.

The areal frequency distribution of manual intervention in the Australasian sector for the duration of the experiment is shown in Fig 5. An aspect of some concern is the very high frequency of intervention which was necessary over the ocean area to the southwest of Australia. This maximum may be directly related to the considerable cyclonic activity which resulted from the presence of a mean trough over the area for a significant portion of the experimental period. Much of this activity was of a relatively small scale, and as might be expected from grid resolution considerations was not accommodated satisfactorily by the hemispheric system. Another factor possibly contributing to the prognosis error was the inability to adequately specify the initial state three dimensional structure of synoptically active features. This difficulty may have been accentuated by spurious boundary effects around pseudo-data regions arising from current analysis procedures above 500 mb.

POLAR STEREOGRAPHIC PROJECTION  
SCALE 1:60,000,000 AT LATITUDE 60°S

COMMONWEALTH METEOROLOGY  
RESEARCH CENTRE  
MELBOURNE

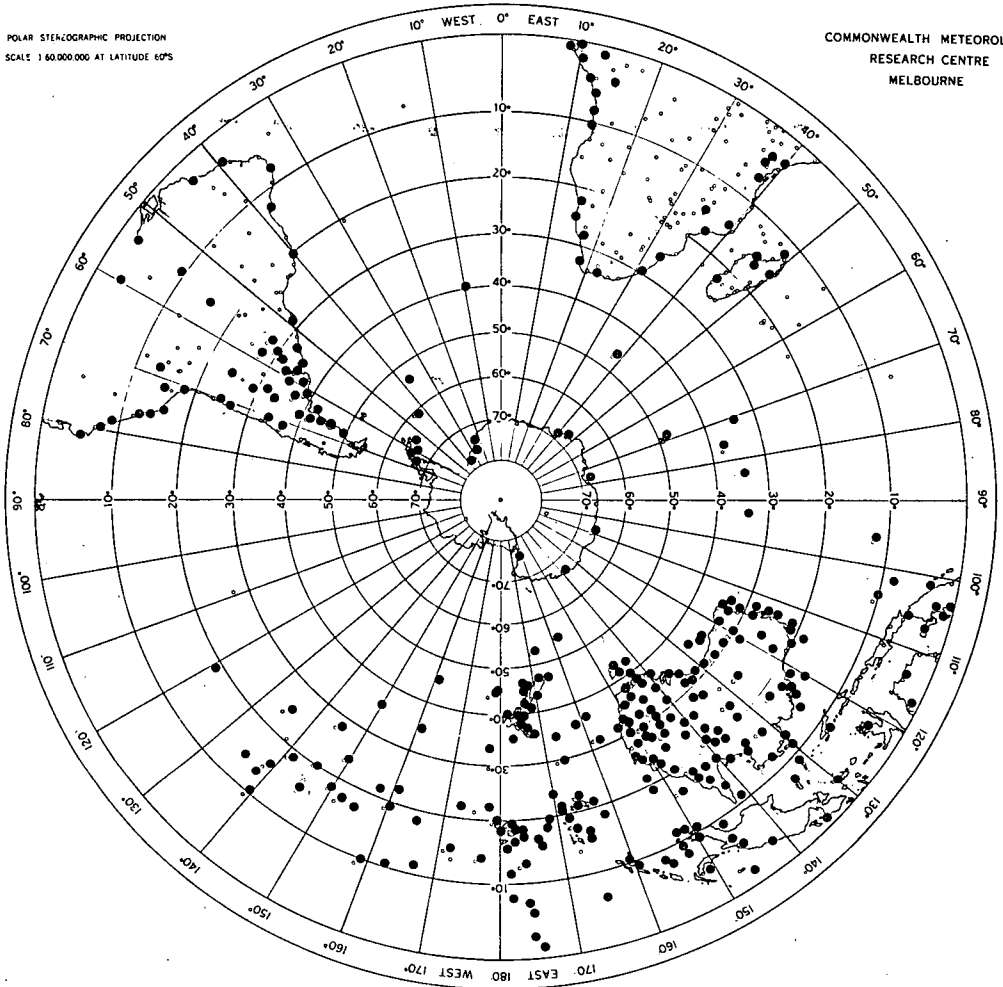


Fig 3 Available MSL observations for 00 Z 28.6.71.

CP 048



POLAR STEREOGRAPHIC PROJECTION  
SCALE 1:60,000,000 AT LATITUDE 60°S

COMMONWEALTH METEOROLOGY  
RESEARCH CENTRE  
MELBOURNE

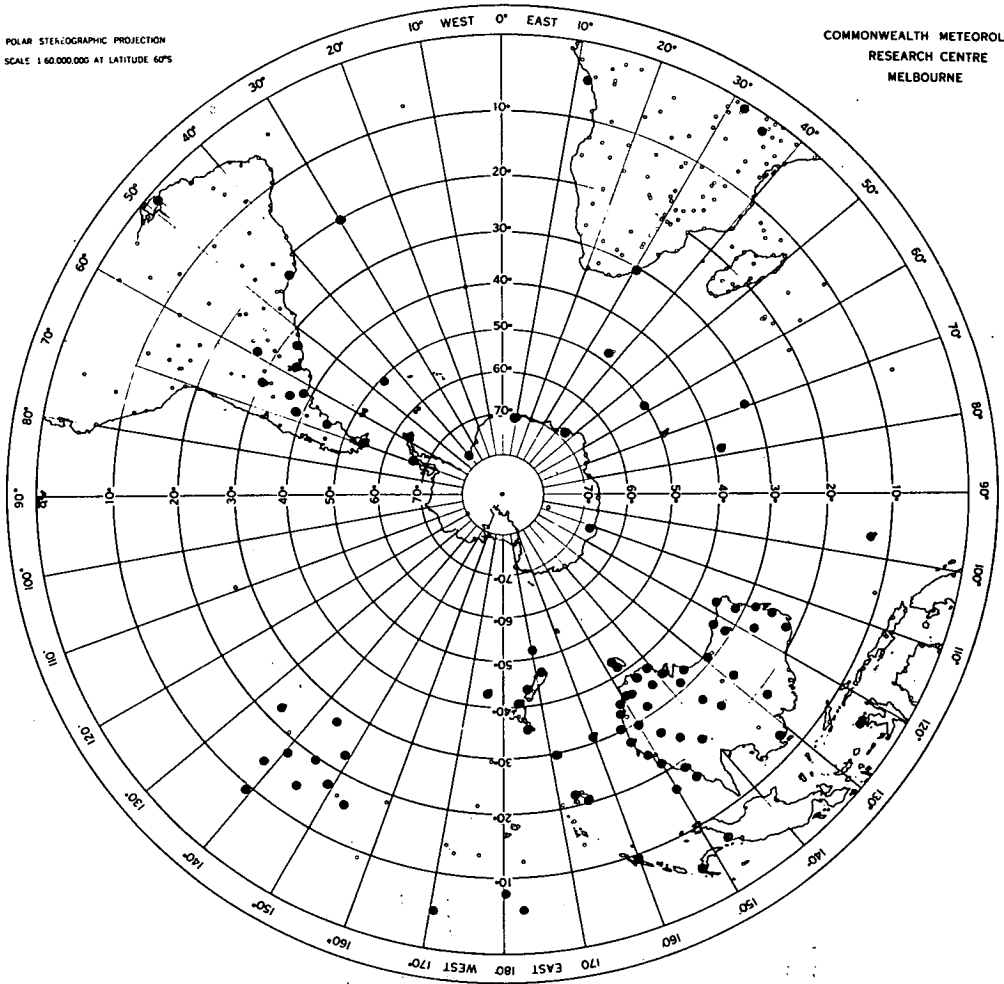


Fig 4 Available 500 mb wind and temperature observations for 00 Z 28.6.71.

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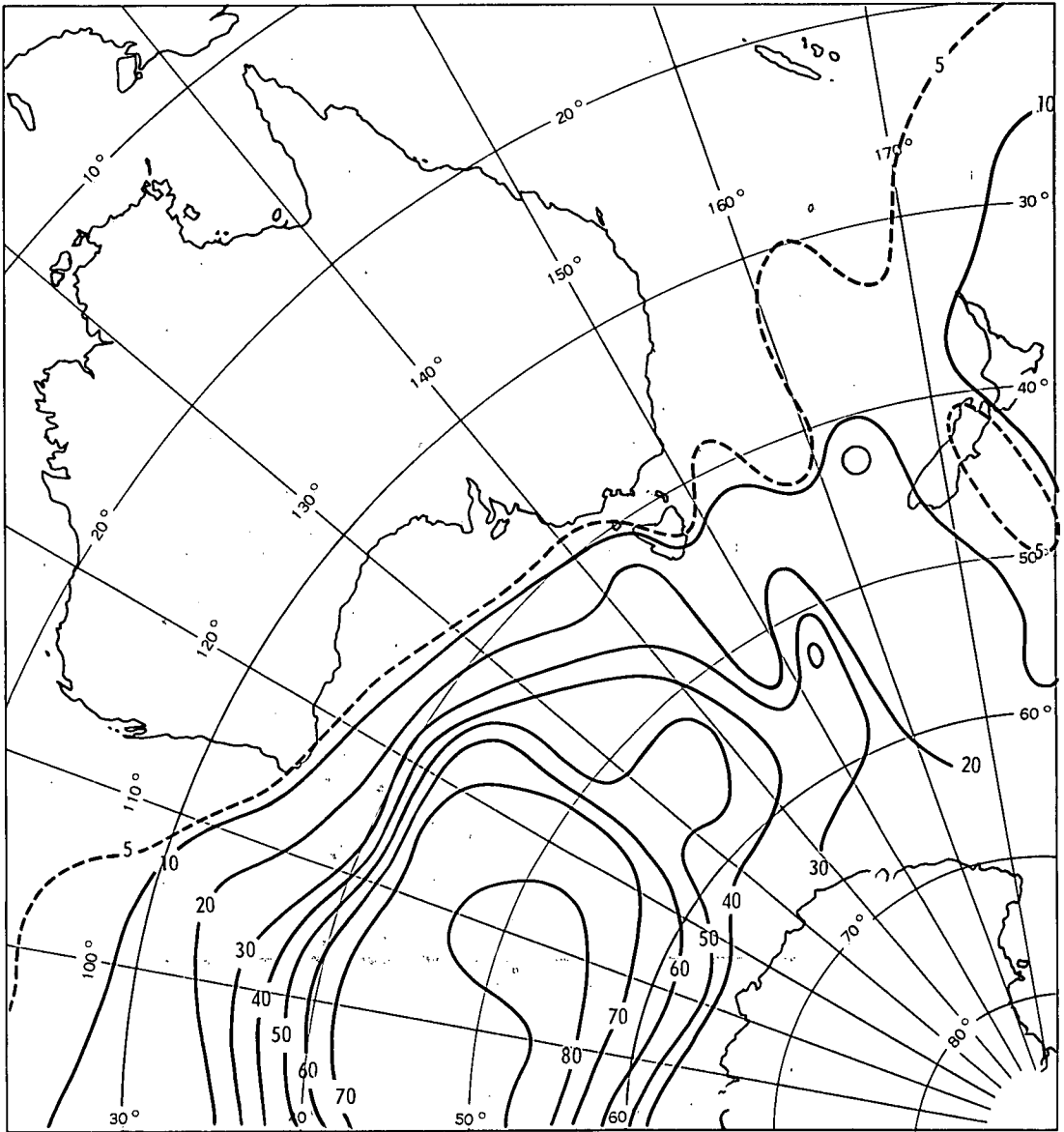


Fig 5 Areal distribution of the percentage number of days on which manual intervention was required in the Australian sector.

## EXPERIMENTAL RESULTS

The synoptic results from the Australian APT region were evaluated as follows:

### 24-hr MSL forecast

Errors of intensity, according to synoptic category, and position associated with MSL 24-hour forecasts are summarised in Tables 1 to 3. A noticeable aspect of these results is the rather high level of accuracy achieved in forecasting the position of mid-latitude troughs and ridges. On approximately 50 percent of observed occasions, the position of such features was forecast to within  $\pm 2$  degrees of the actual position. Individual cyclones, especially those in higher latitudes, were not forecast with the same precision, a bias for S/SE displacement being indicated.

An aspect of some concern is the fairly strong bias over all latitudes for forecast low pressure systems to be weaker than observed. By contrast, the intensity of anticyclones was well predicted with possibly a slight bias toward over-intensification.

Table 1 Synoptic categorization of pressure errors (forecast minus observed) associated with 24-hour MSL forecasts.

Category	Pressure error (mb)					
	-12 to -7 mb	-6 to -3 mb	-2 to +2 mb	3 to 6 mb	7 to 12 mb	$\geq 13$ mb
Troughs at $40^{\circ}$ S (28 cases)	-	2	4	11	11	-
Cyclones between $30^{\circ}$ S and $40^{\circ}$ S (17 cases)	-	-	2	5	8	2
Cyclones between $41^{\circ}$ S and $50^{\circ}$ S (36 cases)	1	1	-	6	14	14
Ridges at $45^{\circ}$ S (27 cases)	-	6	11	3	7	-
Anticyclones between $26^{\circ}$ S and $35^{\circ}$ S (24 cases)	1	6	11	3	1	-

Table 2 Position errors (forecast minus observed), associated with 24-hour MSL forecasts of mid-latitude troughs and ridges.

Category	Position Error ( $^{\circ}$ longitude)				
	$-6^{\circ}$	$-5^{\circ}$ to $-3^{\circ}$	$-2^{\circ}$ to $+2^{\circ}$	$3^{\circ}$ to $5^{\circ}$	$6^{\circ}$ to $10^{\circ}$
Troughs at $40^{\circ}$ S (28 cases)	1	6	16	5	-
Ridges at $45^{\circ}$ S	2	2	14	3	5

Table 3

Position errors of cyclones and anti-cyclones in 24-hour MSL forecasts

Category	Position Error ( $^{\circ}$ latitude from actual centre)				
	$\pm 2^{\circ}$	$\pm 6^{\circ}$	$\pm 10^{\circ}$	$\pm 15^{\circ}$	not retained in forecast
Cyclones between $30^{\circ}$ S and $40^{\circ}$ S	9	4	3	-	-
Cyclones between $41^{\circ}$ S and $50^{\circ}$ S	14	6	2	-	14
Anticyclones between $26^{\circ}$ S and $35^{\circ}$ S	13	7	7	1	-

#### 48-hr MSL forecast

On fourteen occasions predictions were made for 48 hours. Independent subjective assessment over the Australia-New Zealand area rated one forecast as very good, two as good, seven as fair and four as poor. This is a creditable result and invites acceptance of system potential.

#### 24-hr 500 mb forecast

The positions of troughs and ridges were acceptably predicted, no bias being present. There was however a persistent tendency for the amplitude and curvature of troughs to be underestimated. This contributed to much lower than actual wind speed over central and eastern Australia on a number of occasions. In parallel with surface deficiencies, predicted closed lows were always too shallow whilst there was a slight tendency to over-emphasise highs.

#### 48-hr 500 mb forecast

The tendencies noted for 24-hour forecasts were still evident at 48 hours. As a result, there was a tendency for exaggerated zonal flow and a meridional flow weaker than observed.

In summary the above synoptic evaluations suggest that with current data the hemispheric system is capable of providing broad-scale products to 48 hours. However, in general, "development" has not been adequately demonstrated. In the Australian APT region the 500 mb prediction is acceptable for qualitative forecasting of weather provided the foregoing is understood. In this region also the surface prediction is useful to 48 hours.

Fairly typical examples of the current analysis potential of the hemispheric system, bearing in mind the data limitations, and also the restrictions on manual intervention outlined in the previous section, are included at Fig 6 and 7. In order to gauge the consistency of the operational analyses both in the vertical and also in time, analyses for both MSL and 500 mb are included in the figures for consecutive days. As a further evaluation guide, infrared hemispheric mosaics for corresponding synoptic periods are also shown. Care should be taken in the interpretation of the latter, however, due to the asynoptic nature of certain portions of the cloud photograph especially in the Atlantic and Pacific sectors.

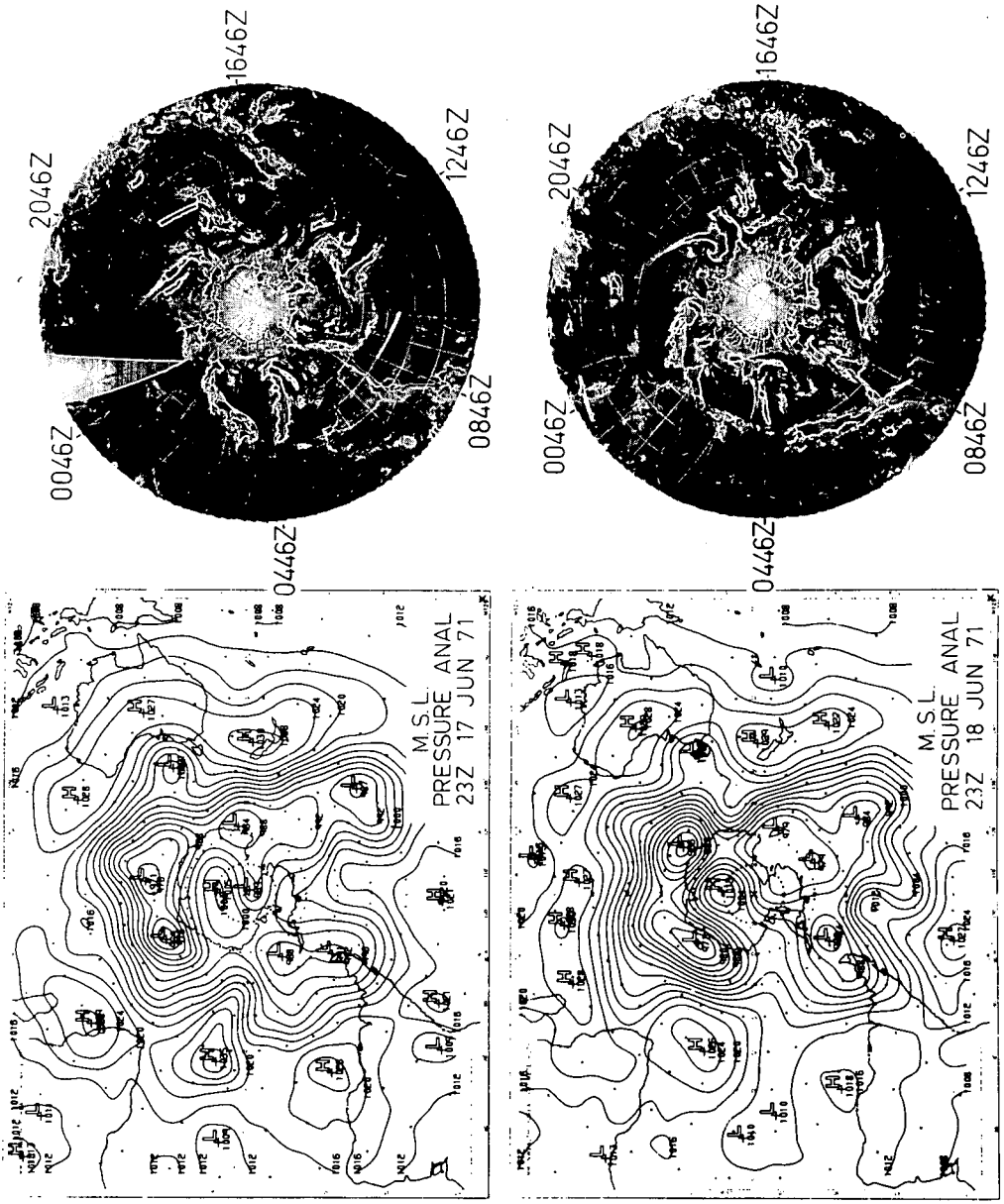


Fig 6 MSL numerical analyses for 23 Z 17.6.71 and 23 Z 18.6.71 with corresponding hemispheric infra-red satellite mosaics.

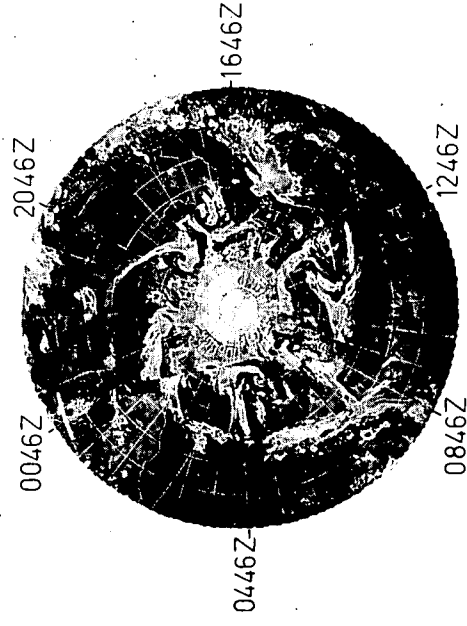
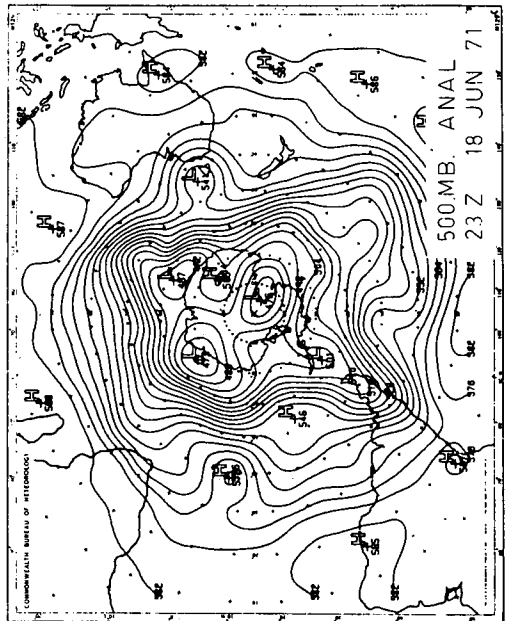
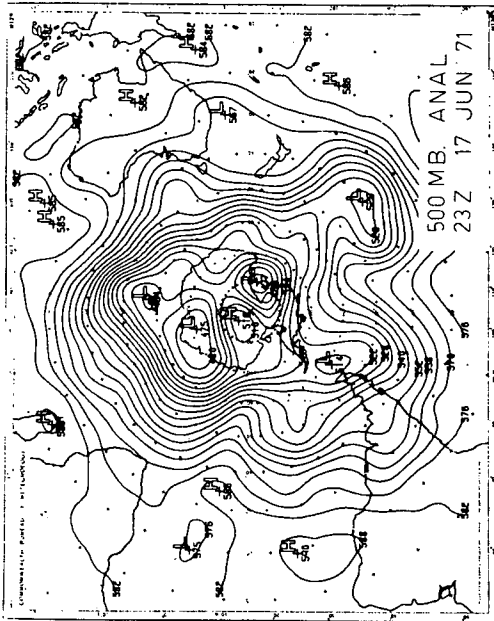


Fig 7 500 mb numerical analyses for 23 Z 17.6.71 and 23 Z 18.6.71 with corresponding hemispheric infra-red satellite mosaics.

From a prognosis viewpoint, Fig 9 is included as an example of the operational 48-hour forecasting potential of the hemispheric system at MSL and 500 mb. In order to facilitate the evaluation, independent verification analyses are also included. The initial MSL and 500 mb analyses are shown in Fig 8. For the Australian region in particular the forecast model shows considerable skill although generally there appears to be a slight reduction in the intensity of individual synoptic systems.

Further evidence of the forecast potential of the hemispheric numerical system may be gauged from Tables 4 and 5 which show mean S1 skill score statistics for 24-hour and 48-hour forecasts over the Australian sector (90°E - 180°E, 15°S - 60°S) (Teweles and Wobus, 1954). Skill over persistence is clearly indicated at all levels except possibly for 48-hour MSL forecasts which, as previously mentioned, were subject to considerable variation in quality.

Table 4 Mean S1 skill score (21 days) for 24-hr forecasts over the Australian sector compared with persistence

Level \ Prognosis method	Numerical Prognosis	Persistence
MSL	55	64
500	43	59
300	40	54

Table 5 Mean S1 skill score (11 days) for 48-hr forecasts over the Australian sector compared with persistence

Level \ Prognosis method	Numerical Prognosis	Persistence
MSL	65	66
500	53	62
300	48	57

A further comparison over a restricted period of six days between forecasts derived from the hemispheric system and the current operational Australian region system is shown in Fig 10. This latter system uses a seven level filtered baroclinic model and operates on a grid of approximately 40 percent higher resolution than the hemispheric system.

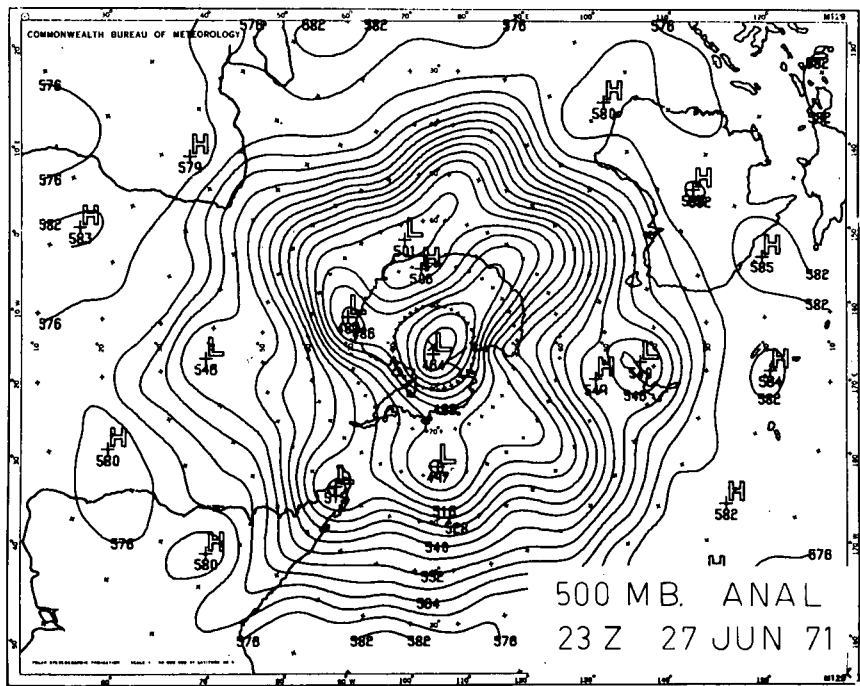
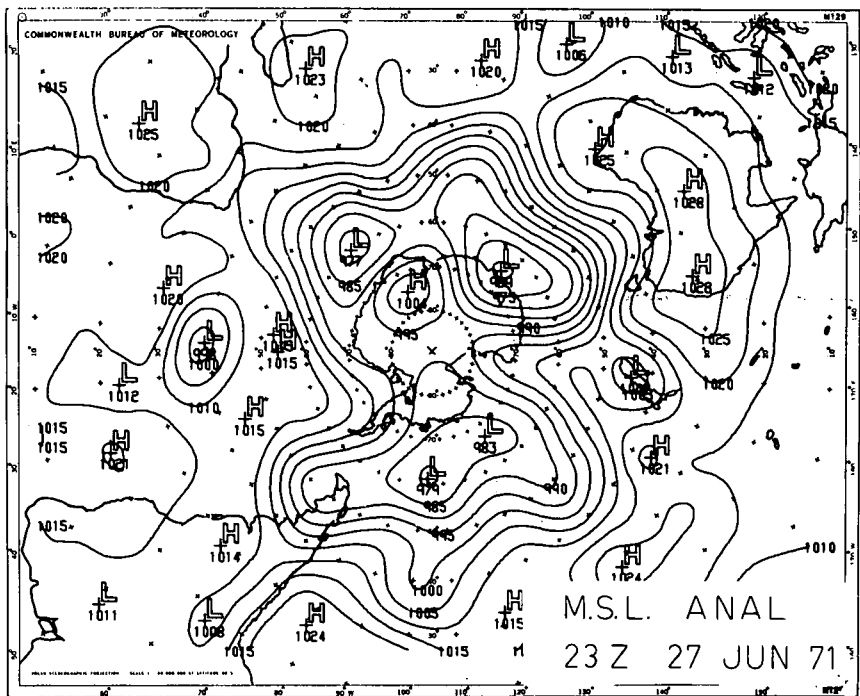


Fig 8 Initial MSL and 500 mb analyses for the 48-hour operational forecast from 23 Z 27.6.71.



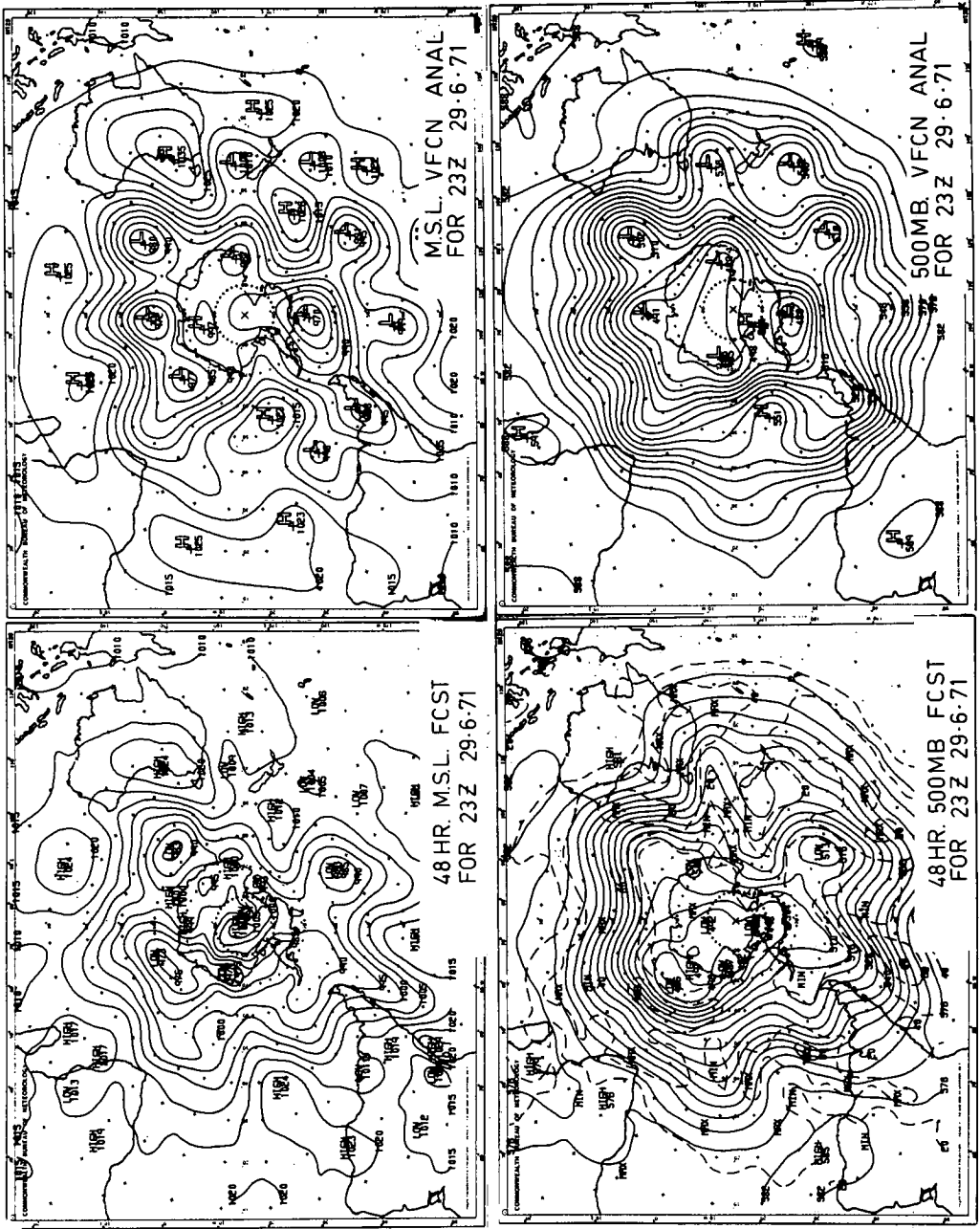


Fig 9 MSL and 500mb 48-hour forecasts together with independent verification analyses for 23 Z 29.6.71.

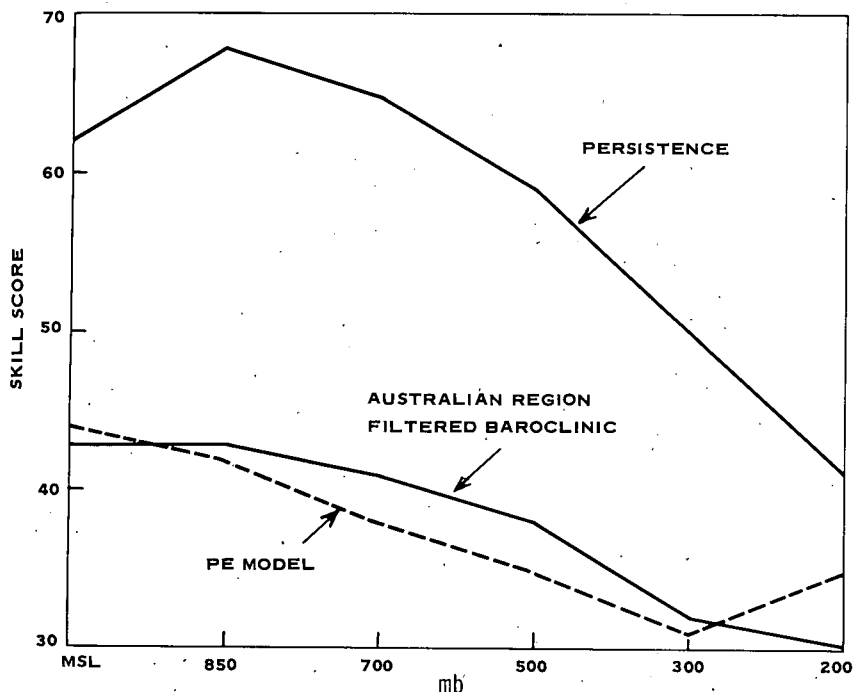
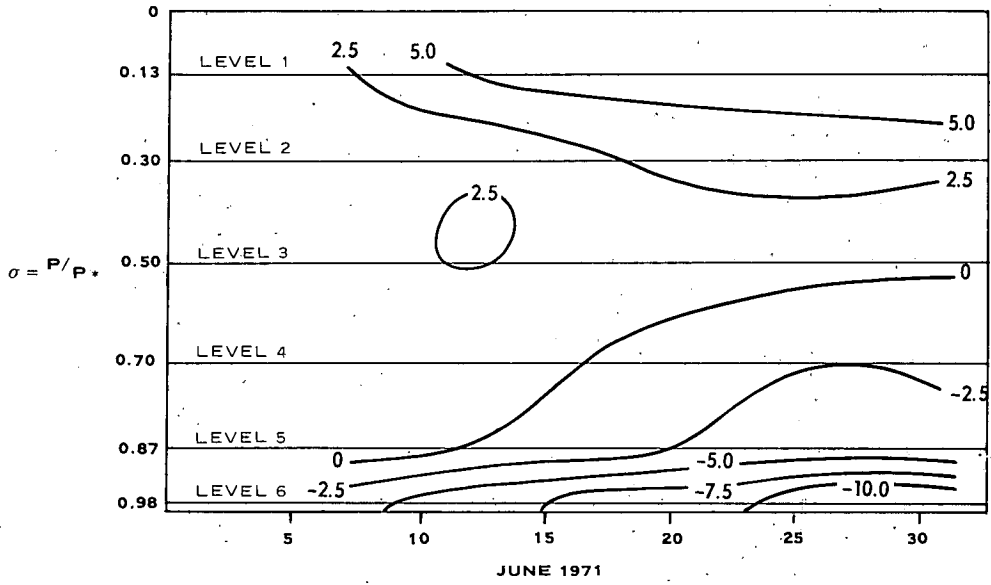


Fig 10 Average S1 skill scores (6 days) for 24-hour forecasts from the PE model and the regional filtered baroclinic model compared with persistence.

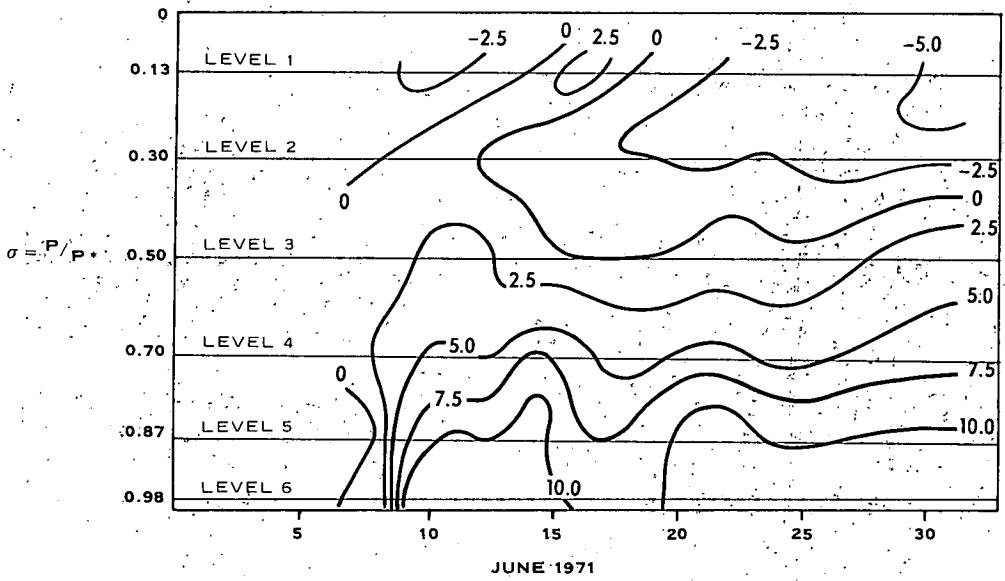
Again both systems display a clear superiority over persistence, although judging from longer term Australian region statistics this margin can be expected to fluctuate considerably. The noticeably inferior performance of the hemispheric system at 200 mb can be explained by vertical resolution difficulties in the hemispheric PE model associated with the definition of the tropopause in middle latitudes.

Other characteristics of the hemispheric system were also monitored. The variation of temperature with time measured in terms of the deviation from the initial state of the zonally averaged temperature for particular latitude bands is shown in Fig 11. The results for two latitude bands are displayed *ie*, the equatorial band  $5^{\circ} - 10^{\circ}S$  and secondly, the polar band  $75^{\circ} - 80^{\circ}S$ .

The initial sudden warming which is most apparent in the polar band is quite spurious and has been traced to an interpolation coding error in the interfacing between the prognosis and analysis models. Correction of the error has subsequently resulted in further synoptic improvement in the predictive skill of the PE model, especially with regard to the location and intensity of middle and high latitude pressure systems.



(a) 5 - 10° S



(b) 75 - 80° S

Fig 11 Variation of the zonally averaged temperature (°C) with time in the hemispheric system for the latitude bands.

The temperature results for the equatorial band display a gradual cooling at lower levels and a warming at higher levels. Initially, in the conditionally unstable tropical atmosphere heat is transported by the convective scheme of the PE model into the middle and upper layers of the atmosphere where, due to the absence of radiational cooling, higher temperatures are maintained for the remainder of the experimental period. By contrast, there is a gradual cooling in the lower levels. This effect is due to the absence in the forecast model of heat and moisture transport from the surface which under normal circumstances would compensate for the advection of cooler southerly air by trade wind mechanisms. As a result MSL pressure was found to gradually rise in low latitudes, stability increased and convection together with associated vertical heat transports were gradually diminished.

Finally, Fig 12 is included in order to provide a gross comparison of the 24-hour forecast temperature errors associated with the CMRC primitive equation model, and also, the USA National Meteorological Center (NMC) primitive equation model developed by Shuman and Hovermale (1968). The NMC statistics, which represent a sample of thirty-three synoptic cases for the spring of 1966 are those given by McDonnell and Newell (1968) and were computed by comparing forecasts with actual observations. The sampling period coincides approximately with the time at which the NMC model achieved operational status. It is therefore interesting to compare limited corresponding statistics (six synoptic cases) for the CMRC model over the Australian region at a comparable development stage, bearing in mind that both models operate at very nearly the same horizontal and vertical resolution. Although no definite conclusions can be drawn from such a comparison it is encouraging that the CMRC model, despite data limitations, appears to be maintaining a performance comparable with the NMC model.

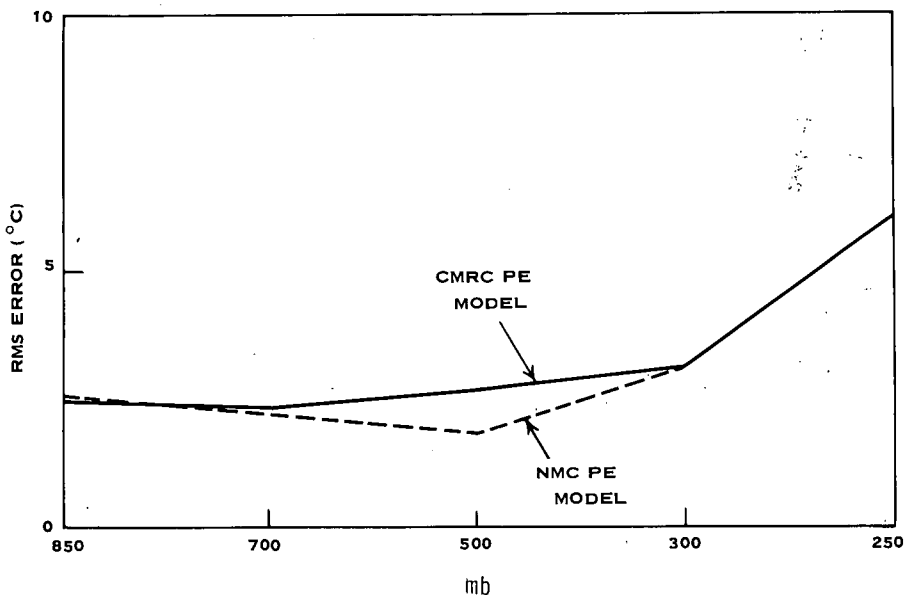


Fig 12 The variation with height of RMS errors associated with 24-hour temperature forecasts from the CMRC and NMC primitive equation models.

## FUTURE PROSPECTS

Although operational benefits from the numerical system will initially be limited due to the constraints imposed by inadequate operating facilities and model deficiencies, the longer term potential of the hemispheric numerical system is viewed with optimism. It is anticipated that high resolution, satellite infrared sounding (SIRS) data will become available on an operational basis in the foreseeable future. These data should considerably enhance the capability of the present system. It is also envisaged that the current numerical system if implemented may assist considerably in the actual introduction of SIRS data in the southern hemisphere by providing suitable first guess temperature fields for the reduction of raw radiance data in the SIRS system.

There is also considerable scope for improving the capability of the models currently incorporated in the hemisphere system. In the near future, radiation will be introduced into the prognosis model together with improved parameterisations for the consideration of boundary layer and convective processes. As a consequence, it is hoped to further consolidate the extended range forecasting potential of the hemispheric system.

## ACKNOWLEDGMENTS

In developing and testing a system as extensive and complex as that described in this paper it is impossible to give individual acknowledgment to all staff involved. The authors, however, are indebted to the ADP division of the Bureau of Meteorology which was responsible for the construction of several of the data processing programs associated with the system, and also, the Services division which diligently performed the actual operational trials. Particular appreciation is directed to Mr. D. Hincksman for his supervisory programming efforts and also to Mr. R. Weinert for general technical support.

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