THE BMRC GLOBAL ASSIMILATION AND PREDICTION SYSTEM

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1. INTRODUCTION

Operational analysis and prediction for the southern hemisphere have been conducted at the Melbourne World Meteorological Centre since 1971. The increase in sophistication of the systems used since that time has paralleled similar developments in the NWP community worldwide. A major limitation in Australia has been availability of requisite computer capacity to support a global system in an operational context although substantial research on global analysis and prediction has been conducted. With the installation of a supercomputer in the Australian Bureau of Meteorology in July 1988 the operational implementation of a comprehensive global assimilation and prediction system has recently been possible. The present paper includes a summary of the performance of this new global system in the first month of its operation. The initial resolution of this system is rhomboidal wave number 31 with nine levels (L9) in the vertical (G31/L9 and H31/L9 denote global and southern hemispheric versions of this system with nine levels); the global G31/L9 system is to replace the current southern hemispheric rhomboidal wave number 21 (H21/L9) system which has been operational since March 1985.

Substantial experimentation with the system has been conducted. Comparisons of analyses and predictions with those produced operationally in the Bureau of Meteorology and at several global centres have been made. We present in the following firstly a discussion of experimental assimilation and prediction concentrating on the month of July 1983 and for which detailed comparisons have been made with products from the European Centre for Medium Range Weather Forecasts (ECMWF). We then present the results of the first month of operational implementation of the BMRC global assimilation system for the month of July 1989.

2. THE BMRC ASSIMILATION AND PREDICTION SYSTEM

The assimilation and prediction system currently in use at BMRC is an extension of the system described by Bourke et al (1982). The scheme was used initially for southern hemisphere impact assessment of drifting buoys and satellite soundings available during FGGE and it subsequently became the operational system for the Bureau of Meteorology southern hemispheric analysis and prediction in March 1985. The system employs intermittent (6 hourly) forward assimilation, univariate analysis and adiabatic non-linear normal mode initialization (NMI). The earliest scheme utilized a successive correction analysis algorithm but this has been replaced by a statistical optimum interpolation (OI) procedure; the analysis is still univariate (bivariate with respect to the zonal and meridional winds) with data insertion being considered in the sequence surface pressure, temperature, moisture and winds. Upon completion of the analysis of the surface pressure field a geostrophic correction to the wind field is derived ; similarly a geostrophic correction to the wind field is made after temperature analysis. The OI scheme for temperature and wind analysis is 3-dimensional and the analysis is performed on the Gaussian transform grid and in the sigma co-ordinates of the spectral model. The moisture analysis is performed with a successive correction scheme.

The present version of the global prediction model has been used primarily at a resolution of G31/L9; some evaluation of G31/L16 has also been conducted. A description of the original model is given in Bourke(1974) and Bourke et al.(1977); more recent refinements are described in Bourke (1988) and Hart et al.(1990). A recent description of the model systematic errors has been given in a study intercomparing the models of the Japan Meteorological Agency (JMA) and BMRC (Tada et al;1989). Briefly the BMRC model includes the following parameterizations : cumulus convection based on the Kuo (1974) scheme with some modifications; shallow convection developed by Tiedtke (1988); the constant flux layer based on the Monin-Obukhov similarity theory as implemented in the scheme developed by Louis (1979); vertical eddy transports of heat, moisture and momentum based on stability dependent diffusive fluxes; radiative processes based on the schemes by Fels and Schwarzkopf (1975) for the longwave radiation and by Lacis and Hansen (1974) for the short- wave radiation with zonally symmetric cloud. Recent model options include parameterization of internal gravity wave drag produced by orographic forcing following the scheme described by Palmer et al. (1986) and the inclusion of an interactive diagnostic cloud scheme which has been used in a number of studies; in the model results to be presented here the two parameterizations of diagnostic cloud and gravity wave drag were not included.

3. EVALUATION OF ASSIMILATION AND PREDICTION FOR THE SOUTHERN HEMISPHERE

Prior to operational implementation the BMRC global assimilation and prediction system has been used in research mode with particular emphasis on analysis and prediction for the July 1983 period. These studies have been directed towards optimizing both the analysis and prediction components of the system. As a benchmark of the performance of analysis and prediction we have used the operational results as available from the ECMWF over the Global Telecommunications System (GTS); additionally the operational analyses for the month ,obtained directly from ECMWF were used in some of these studies to initialise the BMRC model.

An initial investigation compared 4 day predictions from the following experiments for each day of July 1983: the associated experiment identifier is used in the accompanying figures.

Operational ECMWF T63/L15 system (Experiment ES63)

BMRC G31/L9 model initialised with the operational ECMWF analysis (Experiment G31)

BMRC prediction for the southern hemisphere from hemispheric assimilation analyses; here the hemispheric assimilation and prediction system was implemented at both resolutions of H21/L9 and H31/L9 (Experiments H31 and H21)

The time mean of daily mean sea-level pressure and 500 mb geopotential height verification over the 31 cases are shown in Figures 1(a) and (b) for the 20 S to 60 S southern hemisphere latitude band in terms of root-mean-square (RMS) error and bias; the verifications here are against the ECMWF analyses. The two global predictions ES63 and G31 using the ECMWF analysis are clearly superior to either of the hemispheric based predictions; the H31/L9 system yields some small gain at 3 and 4 days relative to the H21/L9 but the distinctive feature of the hemispheric systems at either resolution is the strong cold bias of the error in the 500 mb height prediction. Further predictions were undertaken to clarify the sources of the discrepancies in the hemispheric prediction; an 8 day period from July 8 to 15, 1983 was used to compare predictions from the following;

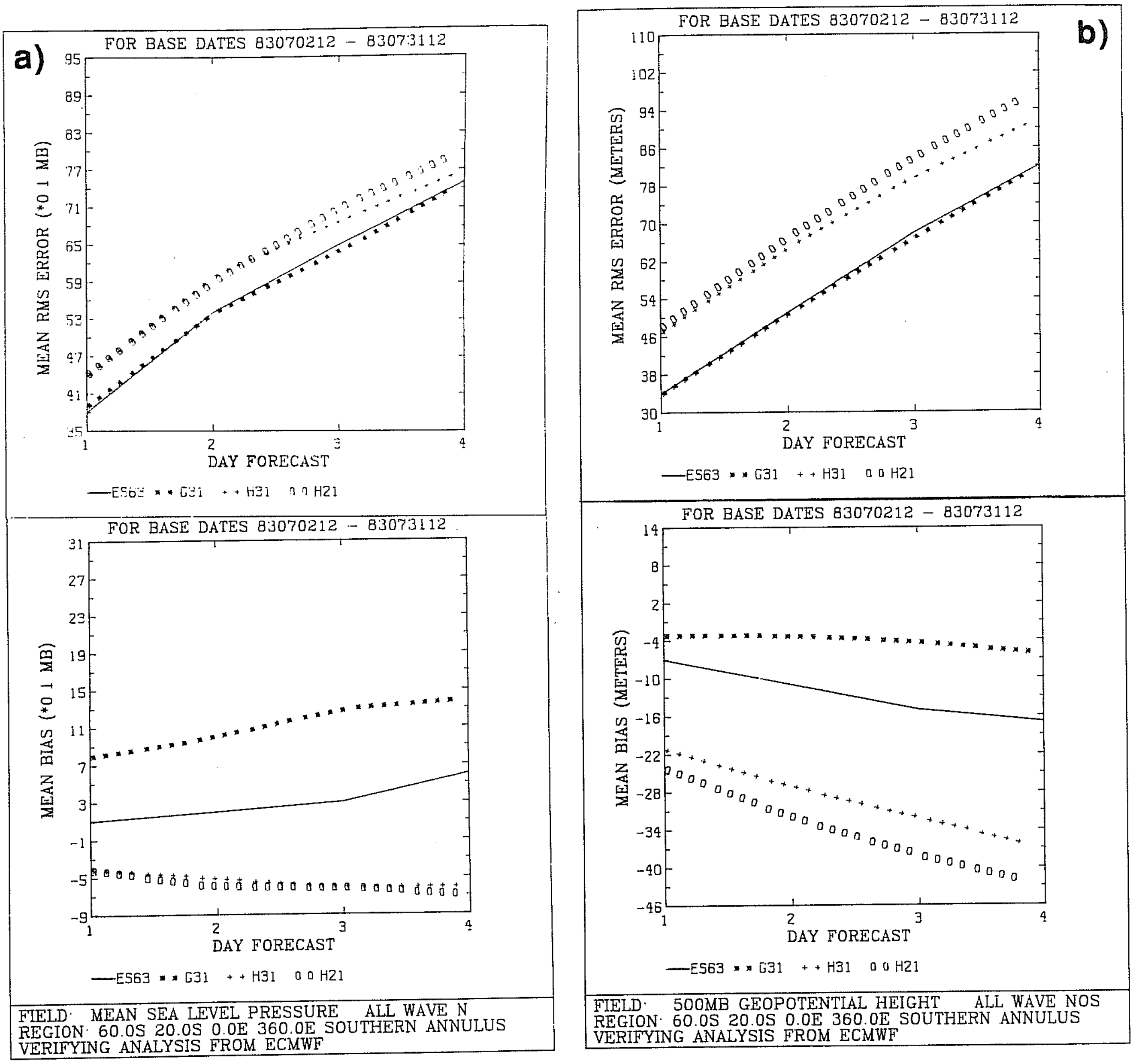


FIGURE 1. (a)
The time mean of daily mean sea-level pressure RMS and BIAS prediction error for the Southern Hemisphere latitude band 20 S to 60 S for the month of July 1983.

ES63 denotes the ECMWF operational T63/L15 prediction
G31 denotes the BMRC G31/L9 prediction model initialized with the ECMWF operational analyses
H21 denotes BMRC southern hemisphere H21/L9 prediction from southern hemisphere H21/L9 assimilation
H31 denotes BMRC southern hemisphere H31/L9 prediction from southern hemisphere H31/L9 assimilation

FIGURE 1.(b)
As in Figure 1.(a) but for 500 mb geopotential height

Southern hemisphere BMRC model (H31/L9) initialised with the southern hemisphere component of the ECMWF analysis (Experiment EH31)

Reanalysis (Single Cycle) with the BMRC (H31/L9) assimilation system in the southern hemisphere with the ECMWF analysis used as a first guess for each of the initial conditions (Experiment EB31).

These two experiments give some indication of the impact of truncating the global initial condition to the southern hemisphere and the impact of the BMRC analysis algorithms using this truncated analysis as a first guess in the 8 case study; in these reanalyses in experiment EB31 the prediction errors in the univariate analysis were not reduced from those usually employed as would be preferable with the implicit improvement of first guess. Figure 2 shows the time mean verifications of the 8 predictions of these EH31 and EB31 experiments for 500 mb height in the southern hemisphere mid-latitudes together with the predictions from this period from the ES63, G31, H21 and H31 experiments. This comparison indicates a gradual deterioration of performance in proceeding from the global initialization of either the BMRC model or the ECMWF model to the hemispheric initialization, the hemispheric re-analysis and finally the hemispheric assimilation and prediction at H31 and H21. The hemispheric truncation of the global initial condition accounts for some increase in bias of the error as does the hemispheric re-analysis. These results indicate that the hemispheric geometry does indeed limit assimilation and prediction performance. The relative impact of the differing analysis procedures is less clearly isolated in these experiments although it is evident that the improved ECMWF global analysis used as a first guess in the EB31 experiment has improved prediction relative to the BMRC H31 assimilation and prediction.

An insight into the cause of the excessive cold bias in the hemispheric assimilation and prediction for July has been obtained from extended 30 day integrations for both the southern hemisphere and global domains initialised from the same initial condition. Figure 3 displays the 30 day mean 500 mb height for hemispheric (H21/L9) and global (G21/L9) integrations from July 1, 1983. The equatorward displacement of the 5760 metre contour line in the H21 integration shows that the climatology of the hemispheric model displays a marked cold bias. This systematic error is attributed to the marked reduction in convective forcing permitted in the southern hemisphere model in July with the intertropical convergence zone and associated warm sea-surface temperatures predominantly outside the model domain. We interpret the overall performance of the hemispheric assimilation and prediction as being substantially influenced by model climatology especially in the tropics with its typically less satisfactory data base and the consequent reliance on model first guess.

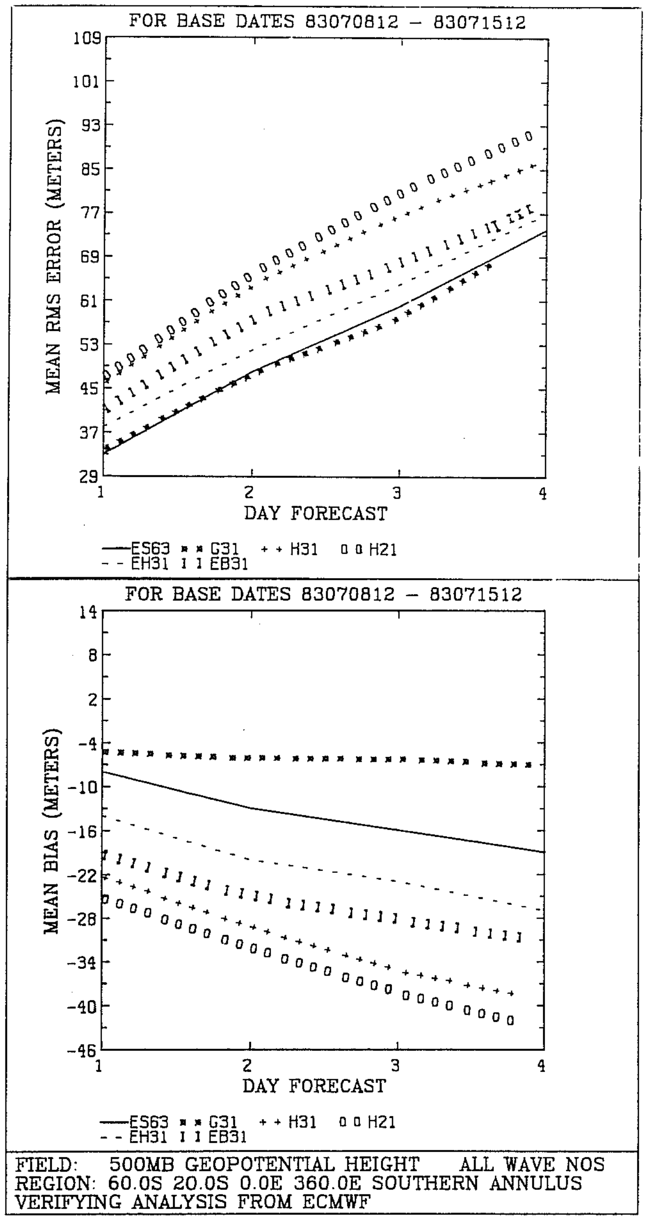


FIGURE 2.

The time mean of 500 mb geopotential height RMS and BIAS prediction error for the Southern Hemisphere latitude band 20 S to 60 S for 8 initial conditions from 8 - 15 of July 1983.

ES63 denotes the ECMWF operational T63/L15 prediction

G31 denotes the BMRC G31/L9 prediction model initialized with the ECMWF operational analyses

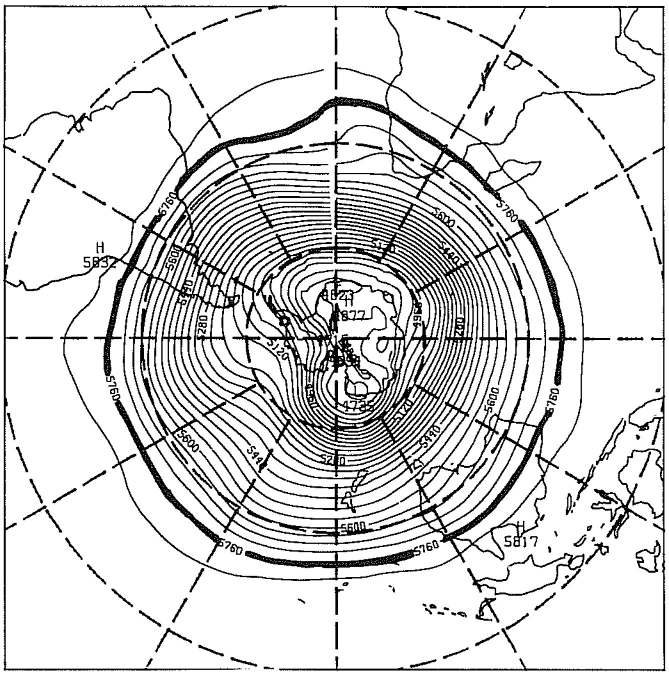
H21 denotes BMRC southern hemisphere H21/L9 prediction from southern hemisphere H21/L9 assimilation analyses

H31 denotes BMRC southern hemisphere H31/L9 prediction from southern hemisphere H31/L9 assimilation analyses

EH31 denotes BMRC southern hemisphere H31/L9 prediction initialised with the southern hemisphere component of the ECMWF analysis at resolution of H31/L9

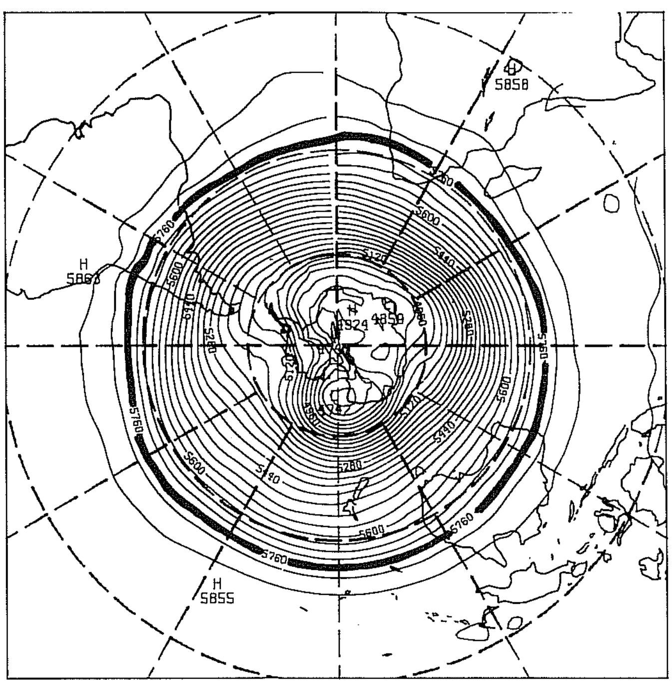
EB31 denotes BMRC southern hemisphere H31/L9 prediction from reanalysis (single cycle) using the H31/L9 assimilation system in the southern hemisphere with the ECMWF analysis used as a first guess for each of the initial conditions

H21 JULY GCM - AVERAGED DAYS 1 TO 30



FORC 500MB HGHT

G21 JULY GCM - AVERAGED DAYS 1 TO 30



FORC 500MB HGHT

FIGURE 3.
The 30 day mean 500 mb height for hemispheric (H21/L9) and global (G21/L9) integrations from July 1, 1983. The 5760 metre contour line is highlighted. (Contour Interval is 40 metres)

At the time these experiments were being performed a global observational data base for July 1983 was not available to BMRC. Accordingly a procedure of quasi-global assimilation and prediction was developed ; here we have initialised the model globally but assimilated with data only in the southern hemisphere prior to global prediction. Figures 4(a) and (b) show the time mean verifications for 14 predictions over the period July 2 to July 15, 1983 for mid latitude southern hemisphere 500 mb geopotential and tropical 200 mb geopotential respectively. The quasi-global assimilation was performed at G21/L9 and G31/L9 denoted as CL11 and QG32 in these figures; the reduction in bias in assimilating data relative to a global model is evident from the comparison with the original hemispheric H21 results also included in these figures. There is a useful reduction in the RMS error in the quasi-global based predictions although the error is still substantially greater than obtained in the global predictions initialized with the ECMWF operational anlaysis. The reduction in convective forcing in the hemispheric system is very evident by the strong cold bias of the 200 mb height prediction in the tropics and the quite large RMS error relative to the quasi-global systems. This quasi-global approach clearly has limitations with the northern hemisphere of the analysis being totally dependent on the evolving model simulation in the absence of data.

The above studies have shown an unambiguous deterioration of southern hemisphere prediction in July when constrained by hemispheric geometry. A comparison of the southern hemisphere climatology in 30 day integrations using hemispheric and global domains for January yielded a bias of the same sign but of less than half the amplitude. We speculate that with the more symmetric distribution of the tropical forcing about the equator in January, the effect of hemispheric geometry is considerably less dramatic in January than in July for the southern hemisphere. Hemispheric and global prediction intercomparisons for the northern hemisphere, where both have been initialized from global assimilation analyses, have shown very small impact from the constraints of hemispheric geometry; the most noticeable difference (although small) was in fact found in the northern hemisphere summer (Arpe and Dittman, 1987); the impact of constraining the assimilation as well as prediction in the northern hemisphere was not considered in that study.

4. GLOBAL ASSIMILATION

The prediction experiments discussed in section 3 were based on the use of ECMWF initial conditions and a range of analyses utilizing the BMRC assimilation and prediction system which was constrained by an unavailability of data in the northern hemisphere. A fully global operational data handling system has been available routinely in

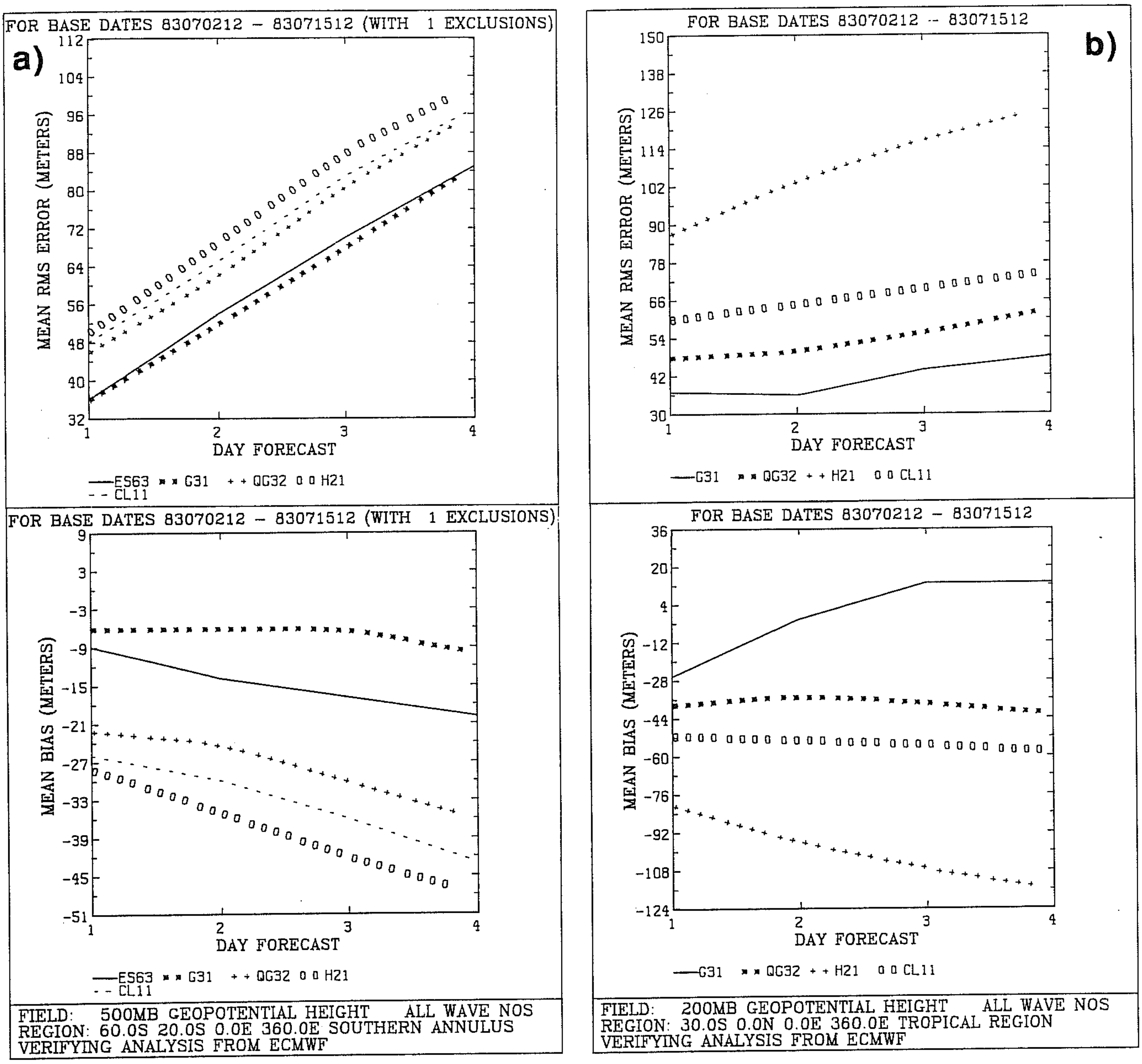


FIGURE 4.(a)
The time mean verifications for 14 predictions over the period July 2 to July 15, 1983 for 500 mb geopotential in the latitude band 20 S to 60 S.

CL11 denotes quasi-global assimilation and prediction at G21/L9
QG32 denotes quasi-global assimilation and prediction at G31/L9
ES63 denotes the ECMWF operational T63/L15 prediction
G31 denotes the BMRC G31/L9 prediction model initialized with the ECMWF operational analyses
H21 denotes BMRC southern hemisphere H21/L9 prediction from southern hemisphere H21/L9 assimilation analyses

FIGURE 4.(b)
As in Figure 4(a) but for 200 mb geopotential in the latitude band 30 S to 0 S

Melbourne since early 1989 and parallel operational testing of global assimilation and prediction has been conducted on a daily basis since July 1, 1989. The global system has been implemented on the ETA10-P computer at a resolution of G31/L9; the assimilation cycle is 6-hourly with predictions being made to 5 days each day from the 12 UTC analysis. At the time of preparation of this paper the most detailed results available are for July 1989 and these are presented in the following; the major intercomparison is with results obtained over the GTS from the National Meteorological Centre, Washington (NMC). Results from other centres are also included where available.

4.1 Data Assimilation Characteristics

The global data base received at Melbourne in July 1989 was incomplete with respect to satellite cloud drift winds. The only northern hemisphere cloud winds received were those produced by JMA for July 1-24 ; for the last week of the month the USA satellite winds were received while Meteosat winds were unavailable for the entire month. The satellite temperature soundings available over the GTS in Melbourne have a horizontal resolution of 500 km; several of the major centres receive satellite soundings at the higher resolution of 250 km.

One indication of the behaviour of the data assimilation system is indicated by RMS observation data fitting statistics for the model 6 hour first guess, the analysis and the initialized analysis. The July 1989 monthly mean observation fitting statistics are shown for the surface pressure in Figure 5(a). Of note here is the large prediction error of the 6 hour first guess in the southern hemisphere relative to that of the northern hemisphere; in addition the initialized analysis in the northern hemisphere is fitting the surface pressure data only marginally better than the model first guess. The monthly mean RMS observation fitting statistics for temperature for July 1989 are shown in figures 5(b) and (c) for the global G31/L9 and the operational hemispheric H21/L9 analysis cycles. It is clear that the global system is providing reduced 6 hour first guess error in the troposphere; with only two levels in the stratosphere at approximately 9 and 70 mb the observational data fitting between 50 and 20 mb reflects large vertical interpolation error associated with attempting to diagnose analyses at these levels with such coarse resolution.

In implementing the global system the prediction error specification has been refined relative to the operational hemispheric H21/L9 system; the prediction errors have been substantially reduced with tighter tolerances on satellite soundings and correspondingly less weight being given to the observations relative to the model first guess in the

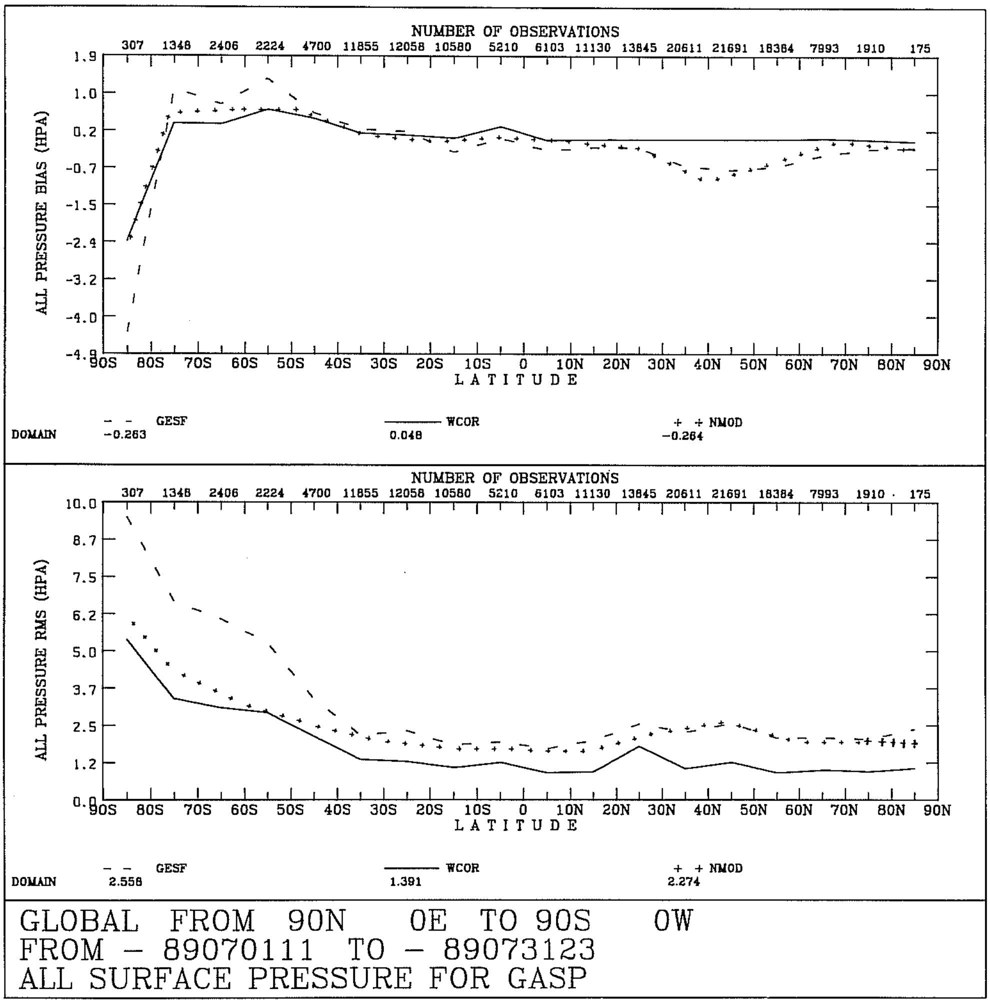


FIGURE 5.(a)
July 1989 time mean of RMS and BIAS observation fitting statistics for mean sea-level pressure observations zonally averaged and displayed as a function of latitude.

GESF denotes statistics relative to 6 hour guess fields
WCOR denotes statistics relative to uninitialized analyses
NMOD denotes statistics relative to initialized analyses

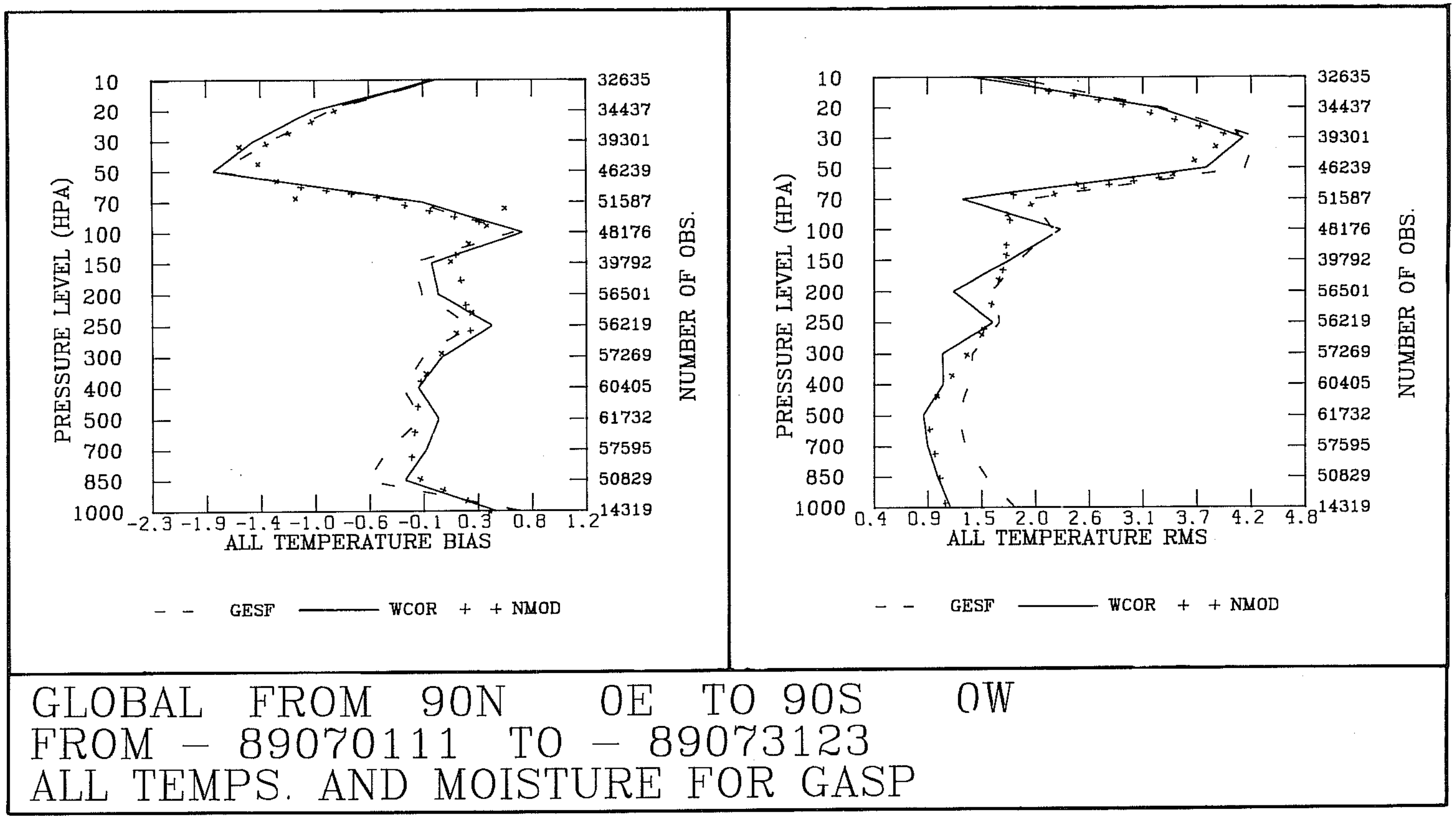


FIGURE 5.(b)
July 1989 time mean of RMS and BIAS observation fitting statistics for temperature observations averaged over the southern hemisphere and displayed as a function of height from the global G31/L9 system.

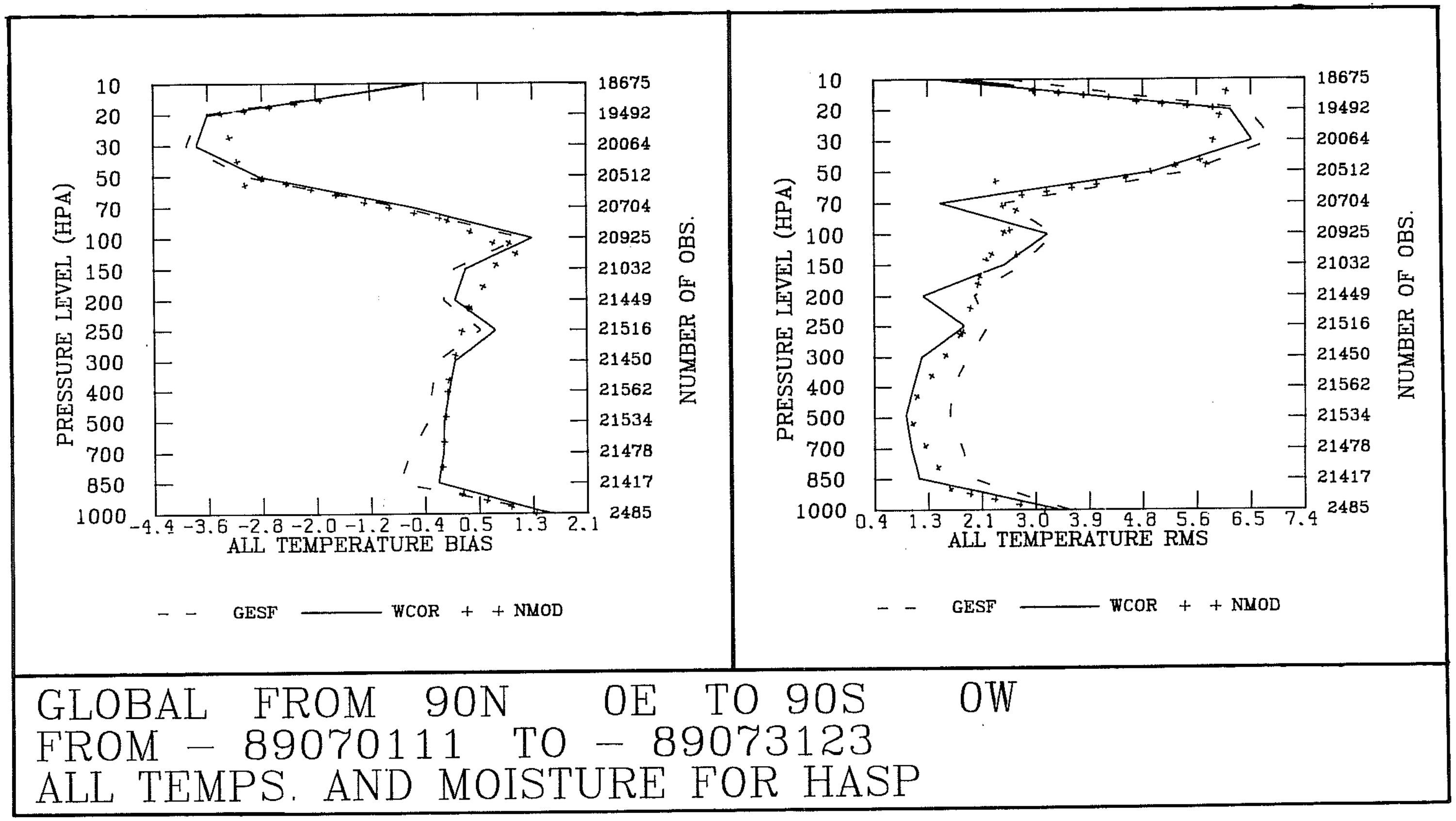


FIGURE 5.(c)
As in Figure 5.(b) but from the southern hemispheric H21/L9 system.

statistical interpolation. The prediction errors used in July 1989 were based on earlier global assimilation cycling analyses during May; the ongoing and further refinement of these error specifications is in progress with some months of operational statistics now becoming available.

As is apparent in Figure 5 there is substantial adjustment in surface pressure analysis during the non-linear normal mode initialization ; the adjustment to temperature and wind analysis is somewhat less. The NMI initialization used here is adiabatic with 3 iterations of the Machenauer (1977) scheme being used to initialise 3 of the 9 vertical modes. A measure of the retention of the analysed increment after initialization is shown in Figure 6 for mean sea-level, 500 mb temperature and 200 mb zonal and meridional wind components; here we have calculated the monthly mean of the correlation between daily analysed and initialized increments and displayed the zonal average of the correlation as a function of latitude. The temperature increment correlation is in excess of .85 except at the highest southern latitudes where there is effectively little or no data while the wind correlations are close to unity. The mean sea-level pressure correlation is clearly less satisfactory with values of 0.4 to 0.5 in the northern hemisphere highlighting this deficiency in our present assimilation scheme. In a subsequent assessment of this relaxation back to the first guess in the northern hemisphere we are refining the prescribed prediction error variances which were initially excessive in the northern hemisphere; we are additionally examining the impact of the sequence of data insertion which is used in this system namely surface pressure, temperature and moisture and then finally winds. Preliminary experiments indicate improved surface pressure data fitting of the initialized analysis when surface pressure is analysed following temperature and wind analysis; with this modification the univariate analysis system still uses a geostrophic correction to the wind field following analysis of surface pressure.

4.2 Time Mean Analyses

The mean July 1989 uninitialized mean sea-level pressure analyses are displayed in Figures 7(a) and (b) as produced in the BMRC global system, and the operational systems of the JMA and NMC (USA) for the southern and northern hemispheres respectively; also shown is the mean difference between the BMRC and NMC analyses; the JMA analysis is only available to us in a graphical form and the projection difference should be noted. The agreement between these three analyses is quite good with discrepancies between BMRC and NMC for example occurring predominantly over high terrain such as the Antarctic, Andes, Himalayas and Rockies. The monthly mean RMS difference between BMRC and NMC uninitialized analyses is shown for mean

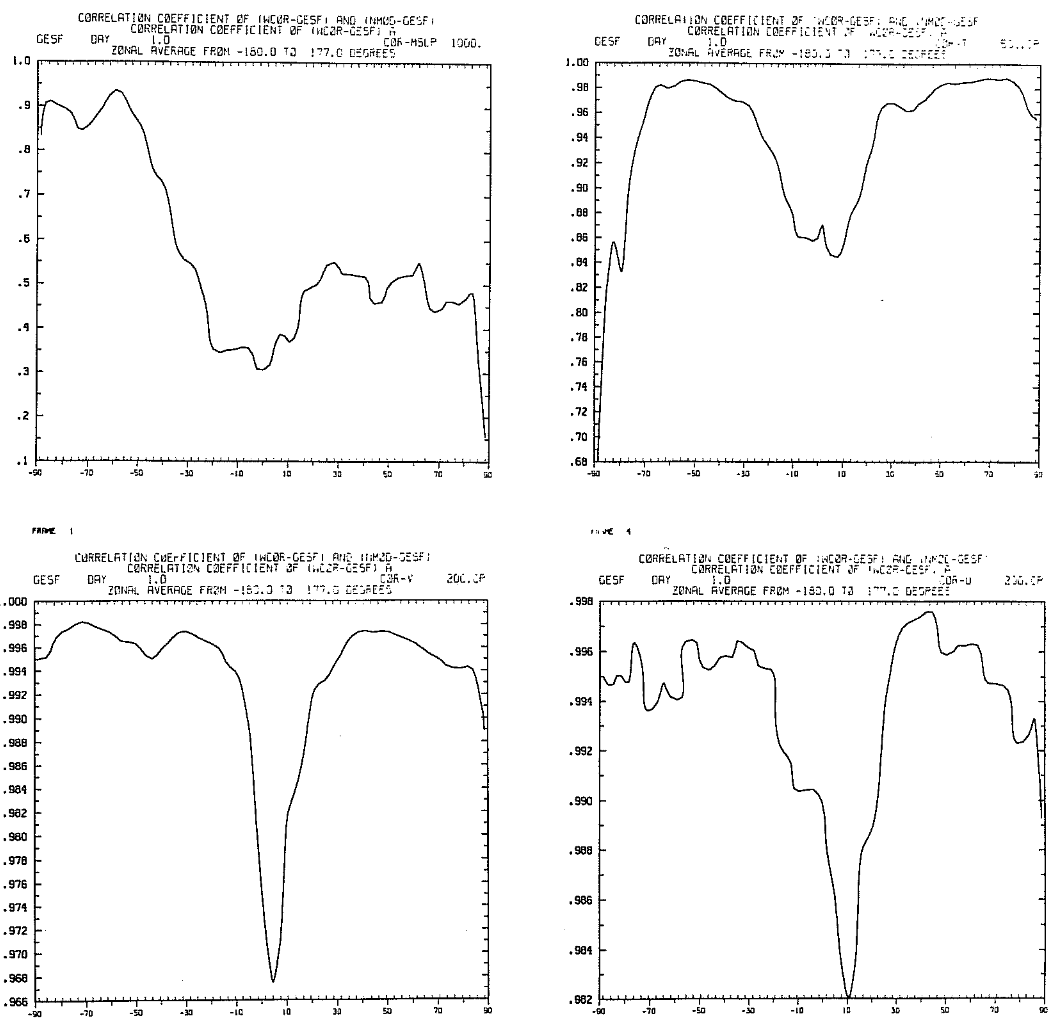


FIGURE 6.

Time mean for month of July 1989 of the correlation between daily analysed and initialized increments.

Top Left: displays correlations in surface pressure increments

Top Right: displays correlations in 500 mb temperature increments

Bottom Left: displays correlations in 200 mb meridional wind increments

Bottom Right: displays correlations in 200 mb zonal wind increments

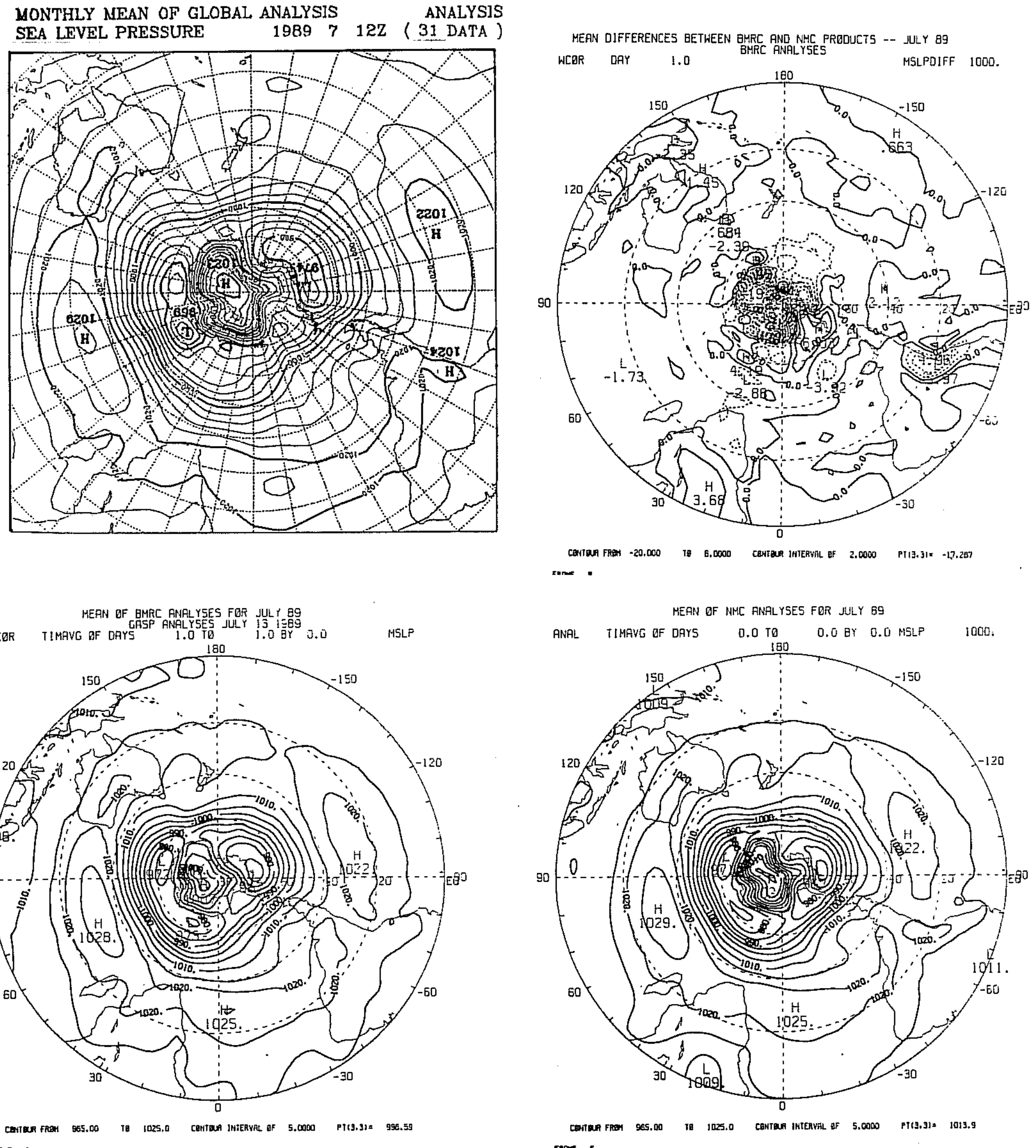


FIGURE 7(a)
The mean July 1989 uninitialized mean sea-level pressure analyses in the southern hemisphere are shown for the global systems with a contour interval of 5 mb.

JMA :	Top Left
BMRC :	Bottom Left
NMC :	Bottom Right

The mean July 1989 analysis difference (BMRC - NMC) is shown at Top Right with a contour interval of 2 mb.

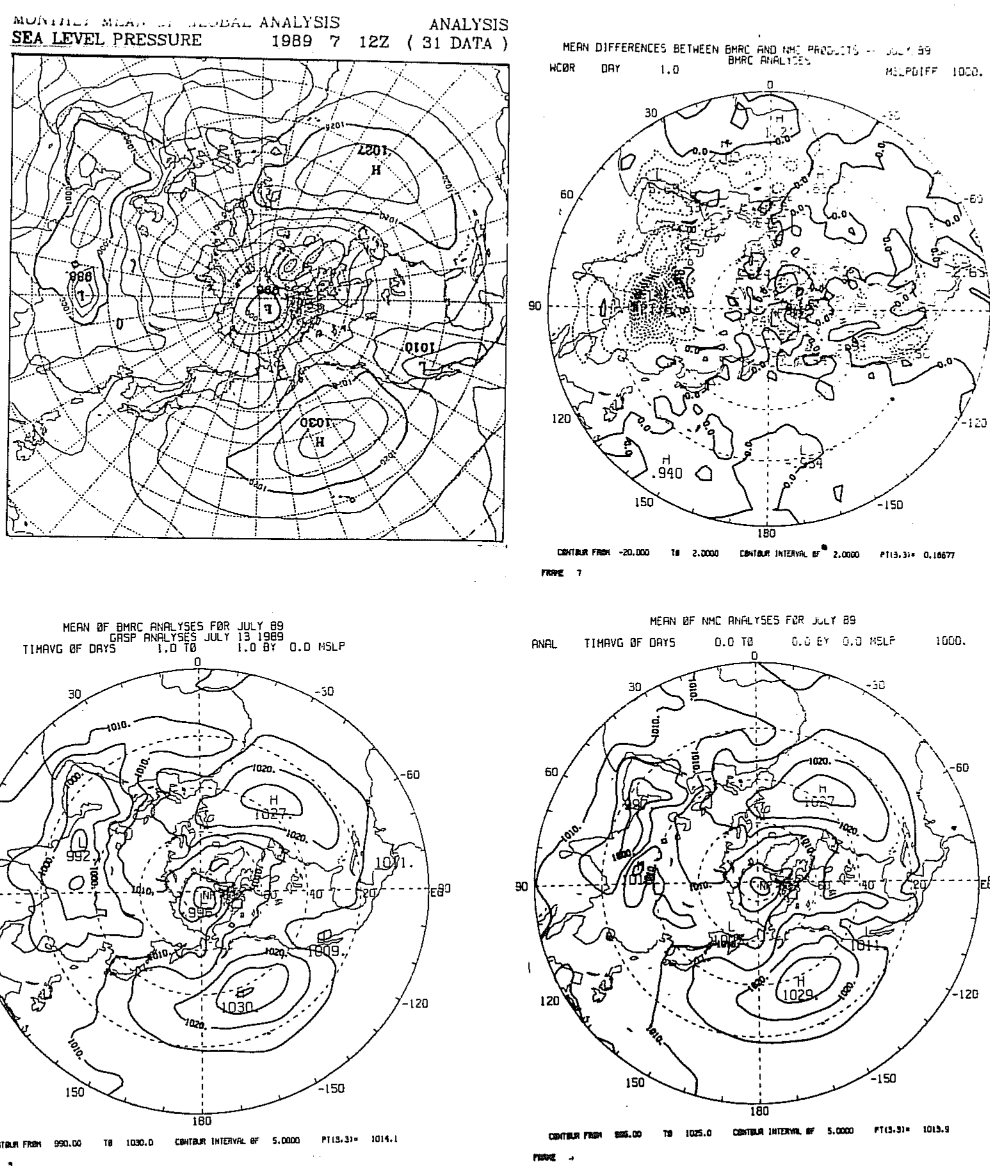


FIGURE 7(b)
As in Figure 7(a) but for the northern hemispshere

sea-level pressure and 500 mb geopotential height in both hemispheres in Figure 8. Again we see the lack of agreement over substantial terrain in both hemispheres. It is noteworthy that the RMS analysis difference in mean sea-level pressure is minimal over the northern hemispheric oceanic areas but quite substantial in the southern hemisphere, with typically a 4 mb difference occurring in the mid to higher latitudes. This highlights the lack of convergence in analysis in the southern hemisphere southern oceans, reflecting the deficiencies in the observing network relative to that of the northern hemisphere. During July 1989 there were approximately 70 drifting buoys measuring mean sea-level pressure in the southern hemisphere. The RMS difference in 500 mb geopotential height also reflects the uncertainty in defining the surface pressure over the southern ocean as well as the discrepancy already noted over high terrain in the mean difference fields.

5. GLOBAL PREDICTION PERFORMANCE

The predictions obtained for July 1989 with the BMRC global system have been compared to those available operationally from the Australian Bureau of Meteorology southern hemisphere system (H21/L9) and from the global systems of NMC (USA), the United Kingdom Meteorological Office (UKMO) and ECMWF as available on the GTS. The results from UKMO and the ECMWF have been included in the intercomparison for the Australian region only. The NMC results are those from the global medium range aviation prediction using a 3 hour data cut-off in analysis and are the most comprehensive data available to us for intercomparison. In the following verifications, the predictions from each centre have been verified against the analyses from that centre.

5.1 Systematic Error Characteristics

The monthly mean systematic and mean RMS error of the 500 mb geopotential height prediction for the southern hemisphere in the BMRC global system are shown in Figure 9 together with the mean analysis and mean 5 day prediction. The comparison of the mean analysis and mean prediction shows a characteristic loss of planetary wave amplitude; the mean error is negatively correlated with the mean analysis showing a typical negative error in the ridges and positive error in the troughs.

The latitude-height cross-section of mean error and RMS error in 5 day prediction averaged over the month is shown in Figure 10 for temperature and wind. It is seen that the model displays the well known systematic error of zonalization of the flow particularly in the intensification of the mid-latitude jet in the southern hemisphere and the enhanced easterlies in the upper tropical troposphere. The temperature bias shows

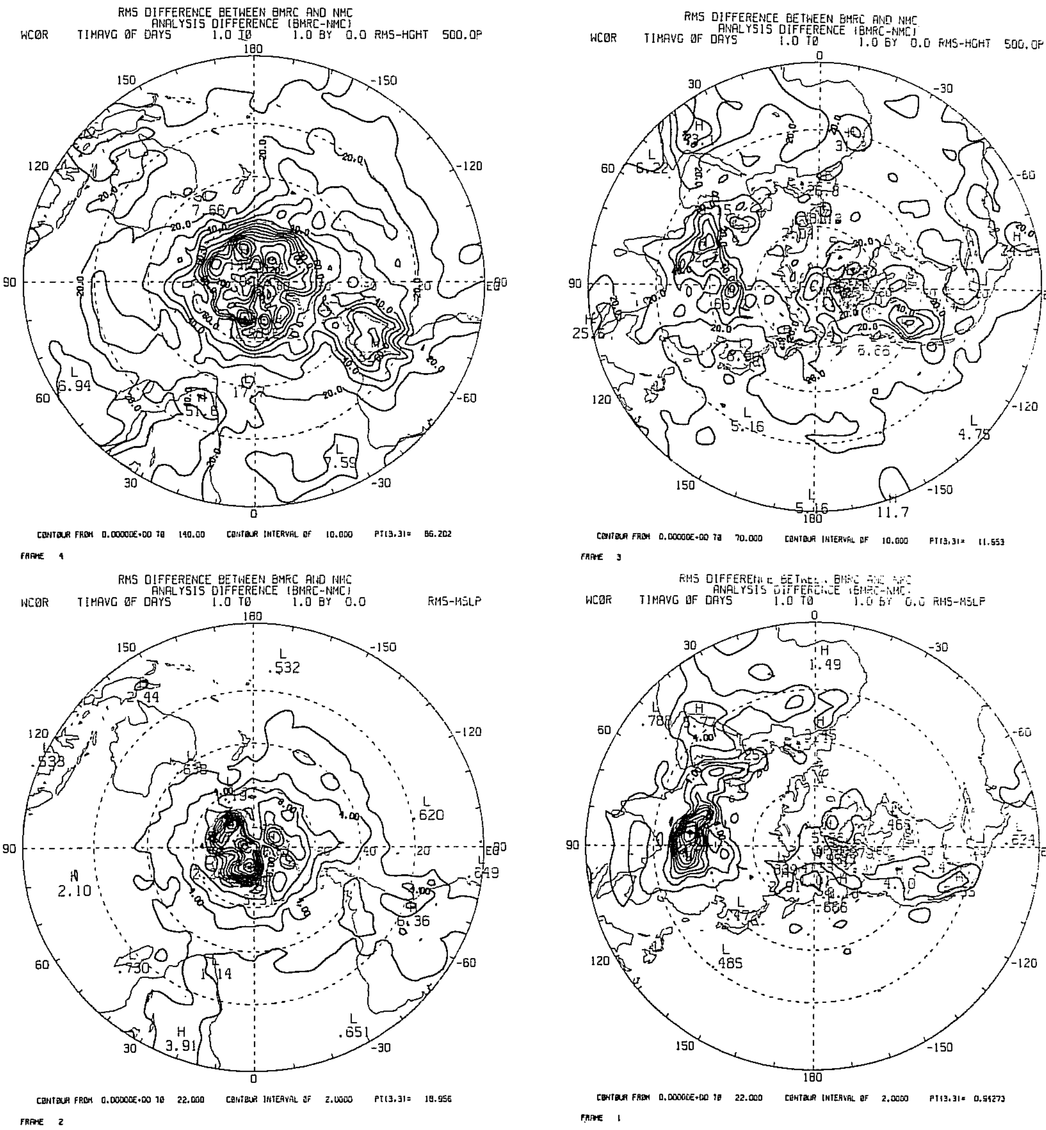


FIGURE 8.

The monthly mean rms difference between BMRC and NMC uninitialized analyses are shown for mean sea-level pressure (Contour interval 2mb) for the

Southern hemisphere : Bottom Left
Northern hemisphere : Bottom Right

The monthly mean rms difference between BMRC and NMC uninitialized analyses are shown for 500 mb geopotential height (Contour Interval 10 metres) for the

Southern hemisphere : Top Left
Northern hemisphere : Top Right

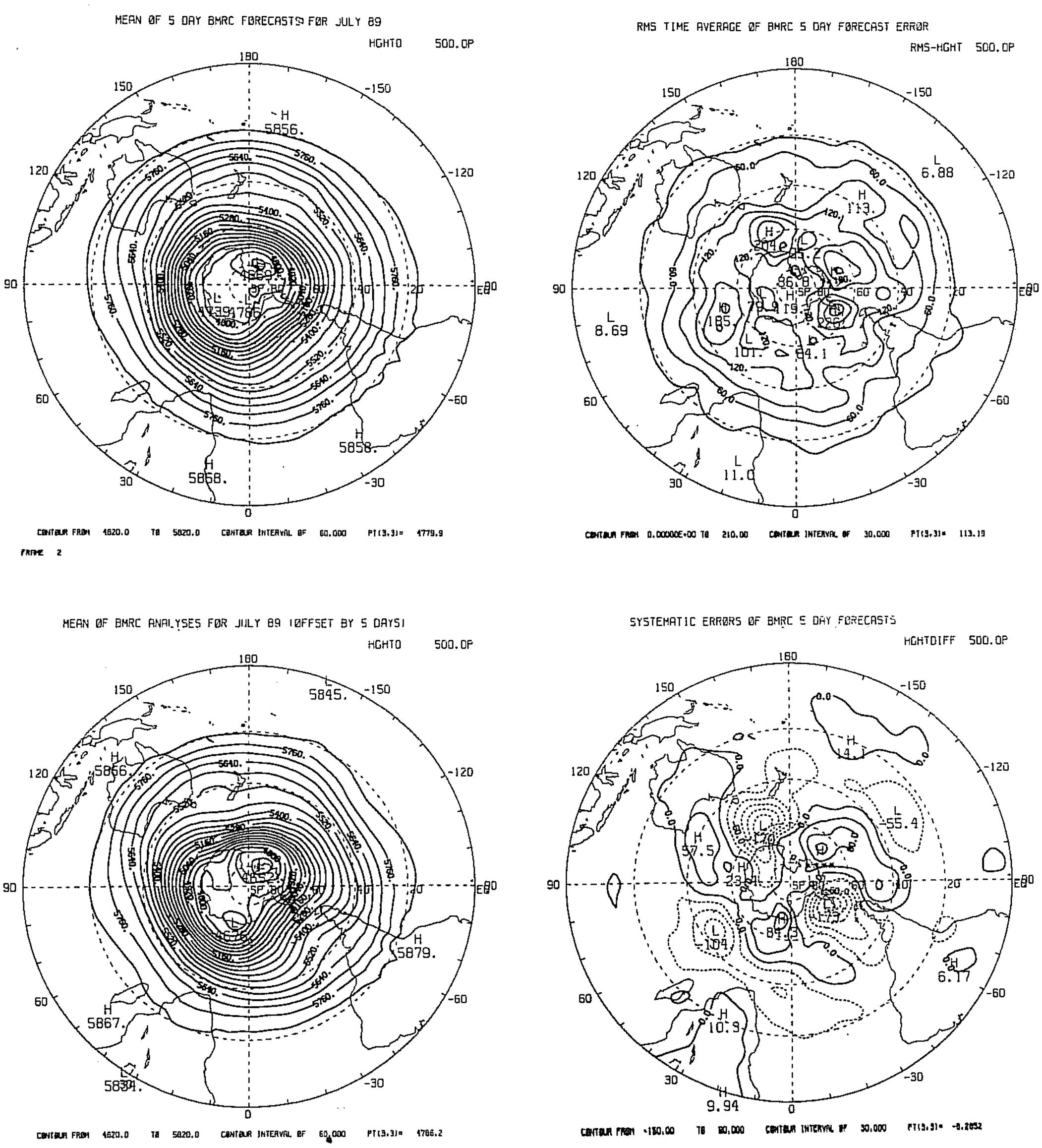


FIGURE 9.
In the southern hemisphere the 500 mb geopotential height field for July 1989 is shown for:

Mean 5 day prediction	: Top Left
Mean Analysis	: Bottom Left
Mean Error of 5 day Prediction	: Bottom Right
Mean RMS error of 5 day Prediction	: Top Right

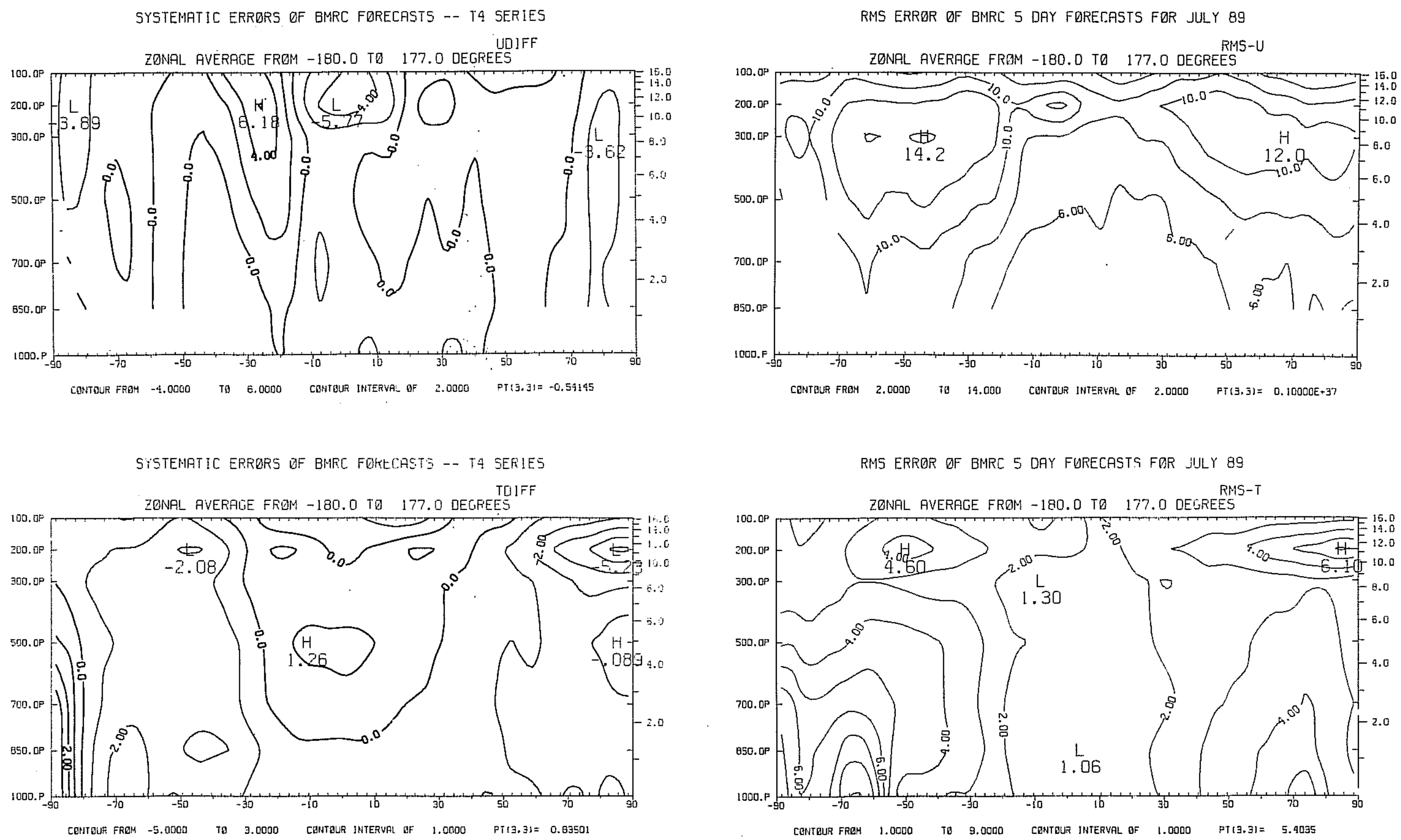


FIGURE 10.
The latitude-height cross-sections of zonally averaged 5 day prediction error is shown for temperature (Contour Interval 1 K) and for zonal wind (contour Interval of 1 m/sec)

Mean Temperature Error : Top Left
Mean Zonal Wind Error : Bottom Left
Mean RMS Temperature Error : Bottom Right
Mean RMS Zonal Wind Error : Top Right

a cold mid-latitude bias in the southern hemisphere and a warm bias in the tropical mid-troposphere. These characteristics were also quite evident in the earlier assessment of systematic error in the BMRC model initialized from ECMWF analyses (Tada et al,1989); however the cold bias in these predictions initialized from analyses more consistent with the prediction model is found to be somewhat less. The RMS errors shown also in Figure 10 give some indication of the total error in contrast to the mean or systematic error.

The hydrologic cycle of the BMRC model has been identified as over-intense showing a characteristic spin-up in precipitation in the above cited study (Tada et al, 1989; see Figure 14). The daily precipitation for each of the 5 day predictions for the month of July 1989 is shown in several cross-sections in Figure 11; the mid-latitude precipitation in both hemispheres is shown in 11(a), that for the tropics in 11(b), with Hovmoller figures as a function of latitude and longitude in 11(c) and 11(d). The precipitation indicated at day 0 in this figure corresponds to that accumulated in the prior 24 hours during the four 6 hour predictions of the assimilation cycle. The dominant overshoot in the precipitation is seen to occur in the tropics and particularly in the eastern hemisphere; the summer hemisphere mid-latitudes show more overshoot than the winter hemisphere mid-latitudes. The zonal average latitudinal profile of precipitation averaged for the month at days 1 and 3 are shown in Figure 12; a characteristic seen here is the increasing latitudinal breadth of the precipitation maximum in the tropics as the integration proceeds. However this latitudinal extension of the precipitation is not as excessive as found in the study by Tada et al.

5.2 Quantitative Verification in the Southern Hemisphere

The 500 mb geopotential height prediction verifications in the southern hemisphere mid-latitudes for the three systems H21/L9, G31/L9 and NMC (T80/L18) in July 1989 are shown

> as a time series of the anomaly correlation over the month at days 1 to 4 in Figure 13 (a) ; and for

> the mean over the month in terms of RMS, anomaly correlation, S1 skill score and bias in Figure 13 (b).

The current hemispheric operational system is integrated to only 2 days reflecting computational and performance limitations of this system. The variability of the hemispheric system at days 1 and 2 is clearly much greater than that of either of the global systems and the prediction performance is substantially inferior. The NMC

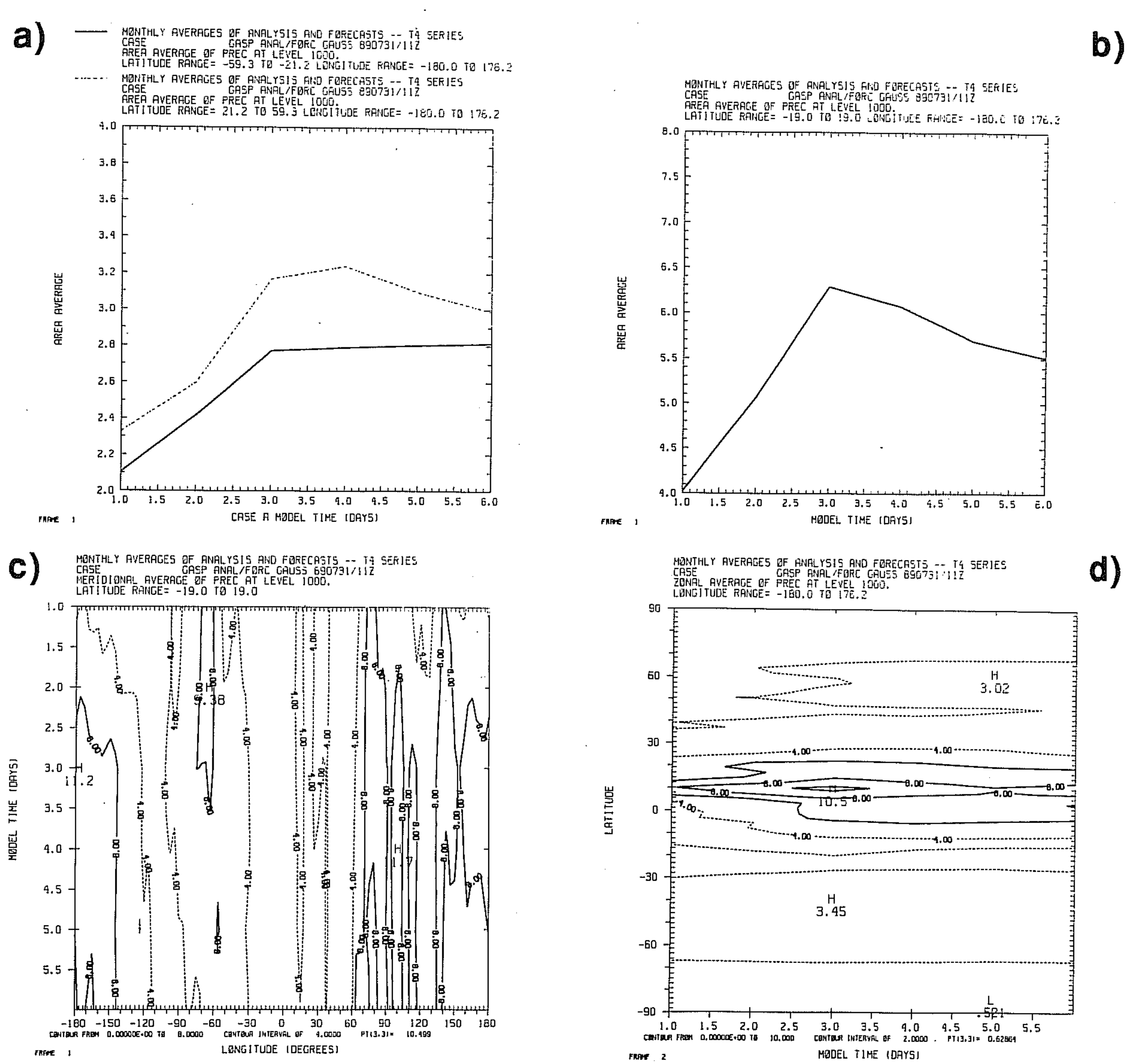
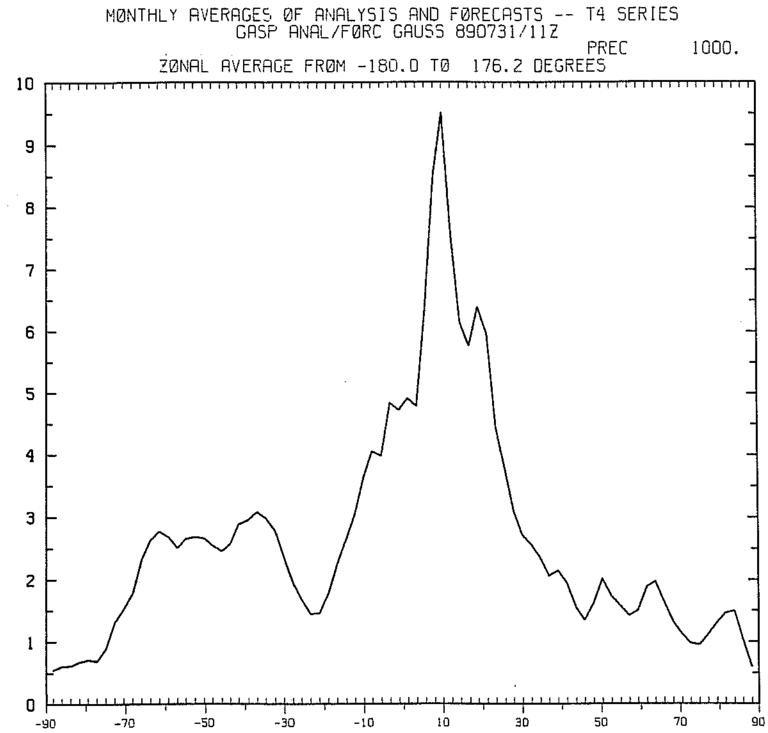


FIGURE 11.
The daily precipitation in mm/day for each of the 5 day predictions averaged for the month of July 1989 is shown for

(a) Area averaged mid-latitude bands 20 N to 60 N (Dashed) and 20 S to 60 S (Solid) precipitation
(b) Area averaged tropical band 20 S to 20 N
(c) Averaged in tropical band 20 S to 20 N as a function of longitude
(d) Averaged in longitudinal band 0 to 360 as a function of latitude



FRAME 4

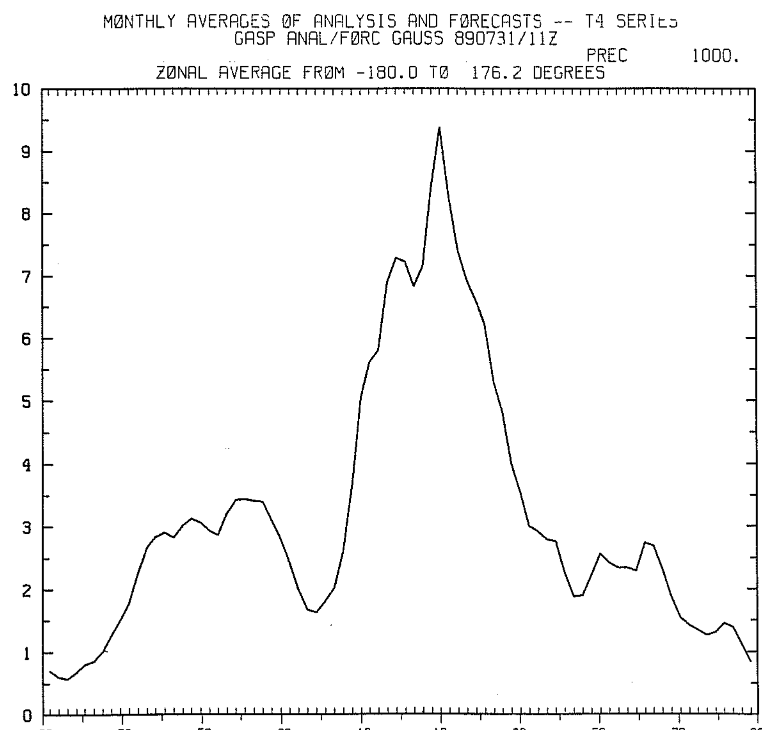


FIGURE 12
The zonal average latitudinal profile of precipitation averaged for the month are shown in mm/day for:

Day 0-1 accumulation : Upper
Day 4-5 accumulation : Lower

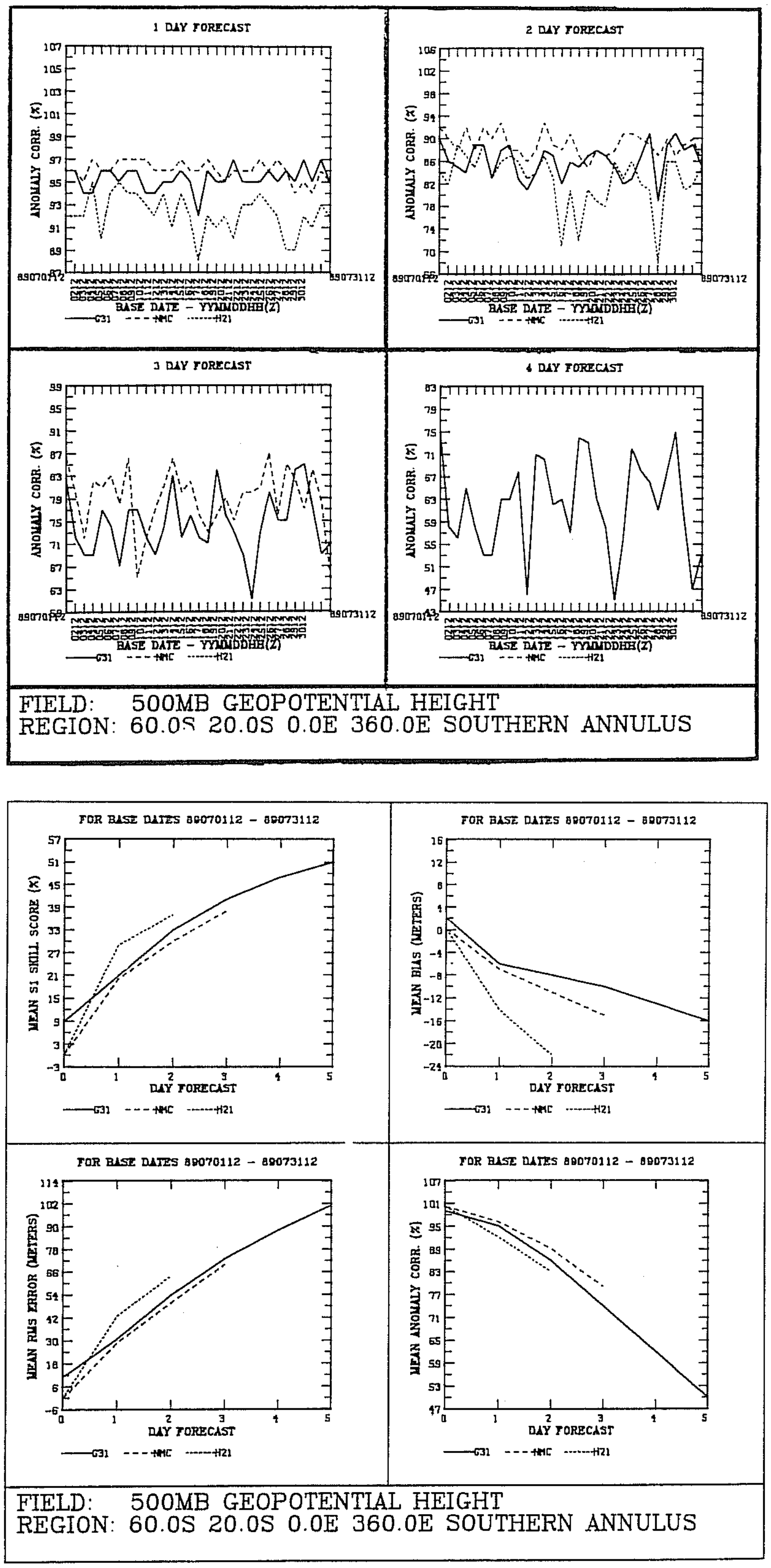
a)
b)


FIGURE 13

(a)Southern hemisphere 500 mb geopotential height prediction verifications in the mid-latitude band 20 S to 60 S for the three systems H21/L9, G31/L9 and NMC (T80/L18) in July 1989 are shown as a time series of the anomaly correlation over the month from days 1 to 4.

(b)As in 13(a) but shown as the mean over the month in terms of RMS, anomaly correlation, S1 skill score and bias.

prediction is the most satisfactory of the three systems although in terms of RMS error there is little difference between NMC and G31/L9. It is noteworthy that the negative temperature bias prediction is substantially larger in the H21/L9 system reflecting the results obtained in our earlier experimentation comparing quasi-global, global and hemispheric systems.(In Figure 13(b) the G31/L9 verification at time zero is between the initialized model and uninitialized analyses.) The character of the temperature bias in the two global systems is quite similar which is no doubt related to the similarity in physical parameterizations in common use e.g. the Fels-Schwarzkopf radiation scheme and Kuo convective scheme. The G31/L9 prediction retains an anomaly correlation above 0.6 until day 4; relative to the operational capability of the hemispheric system the global system is providing a substantial upgrade in prediction performance. The verification of prediction of wind at both 500 and 200 mb in the southern hemisphere (not shown) is consistently improved in the global system relative to the hemispheric.

5.3 Quantitative Verification in the Northern Hemisphere

The 500 mb geopotential height prediction verifications in the northern hemisphere mid-latitudes for the two systems G31/L9 and NMC are shown in Figure 14 as a time series of the anomaly correlation over the month for days 1 to 4. The performance of the NMC system is clearly superior to that of the BMRC system especially in the first third of the month. The overall level of an anomaly correlation well above 0.6 at day 4 indicates that useful prediction skill is available from this first attempt at prediction in the northern hemisphere with the BMRC system.

5.4 Quantitative Verification in the Australian Region

The July 1989 predictions in the Australian region have been compared from five different systems; namely those available operationally from the Australian Bureau of Meteorology southern hemisphere system (H21/L9), from the global systems of NMC (USA), the United Kingdom Meteorological Office (UKMO) and ECMWF as available on the GTS and from the BMRC global system. From these five systems we show the time mean RMS error and bias in 500 mb geopotential height prediction in the Australian Region in Figures 15 (a) and (b) respectively. The ECMWF system is clearly providing the superior prediction, with UKMO, NMC and BMRC producing rather equivalent results; the hemispheric system is the least satisfactory prediction. The bias in these forecasts illustrates further the similarity between the BMRC and NMC systems and the larger cold bias associated with the hemispheric system. The ECMWF and UKMO systems are producing a similar positive bias in the 5 day predictions.

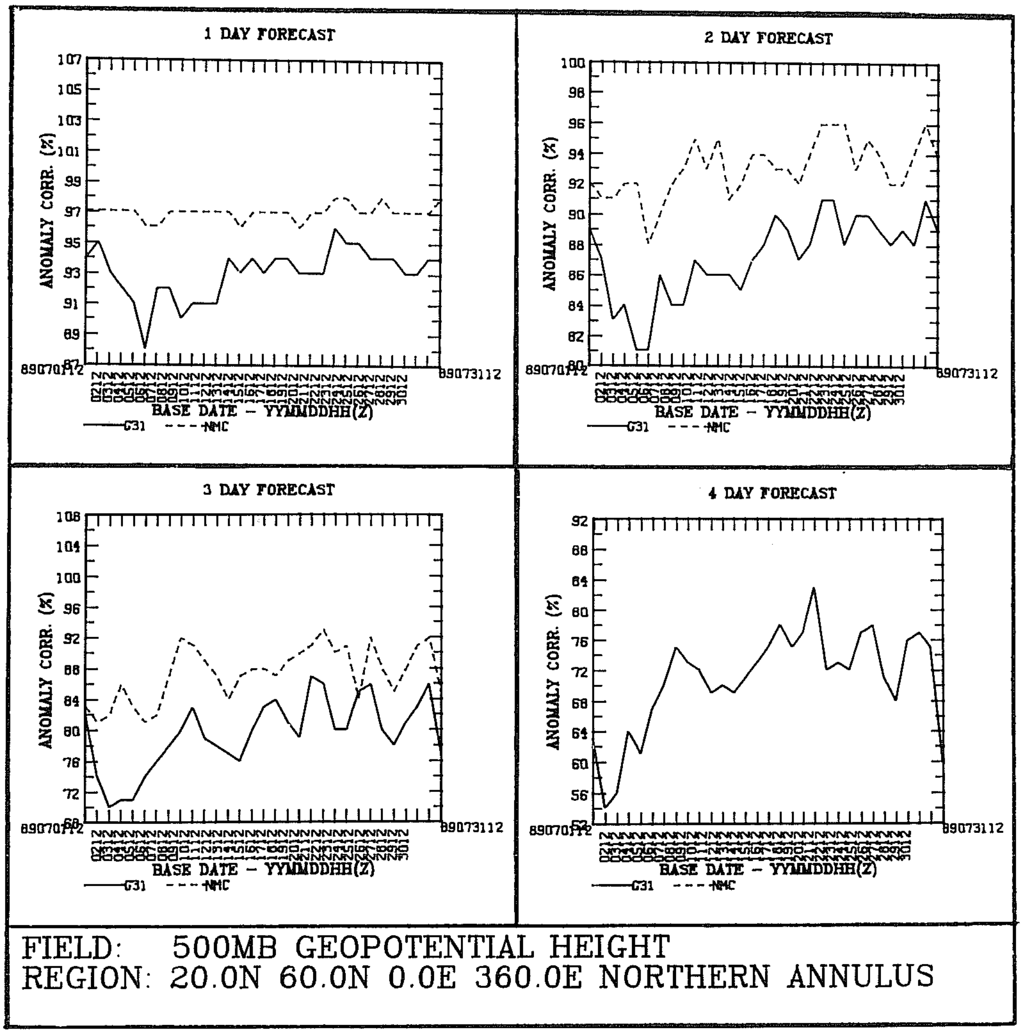
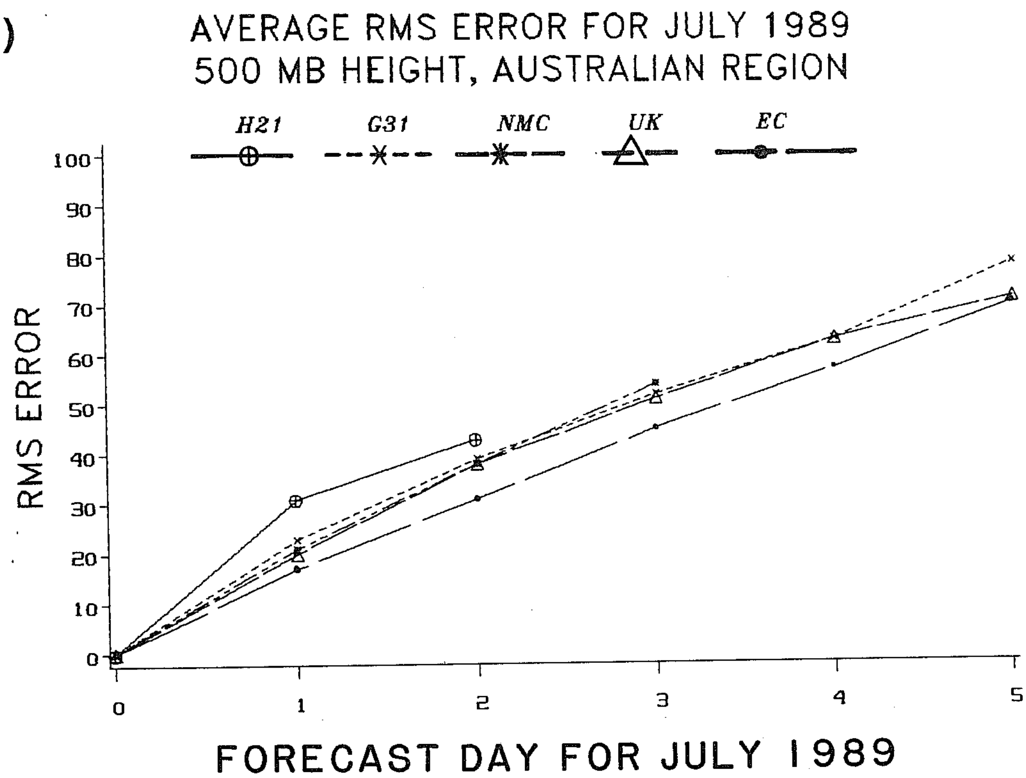


FIGURE 14

Northern hemisphere 500 mb geopotential height prediction verifications in the mid-latitude band 20 N to 60 N for the two systems G31/L9 and NMC (T80/L18) in July 1989 are shown as a time series of the anomaly correlation over the month from days 1 to 4.

a)



b)

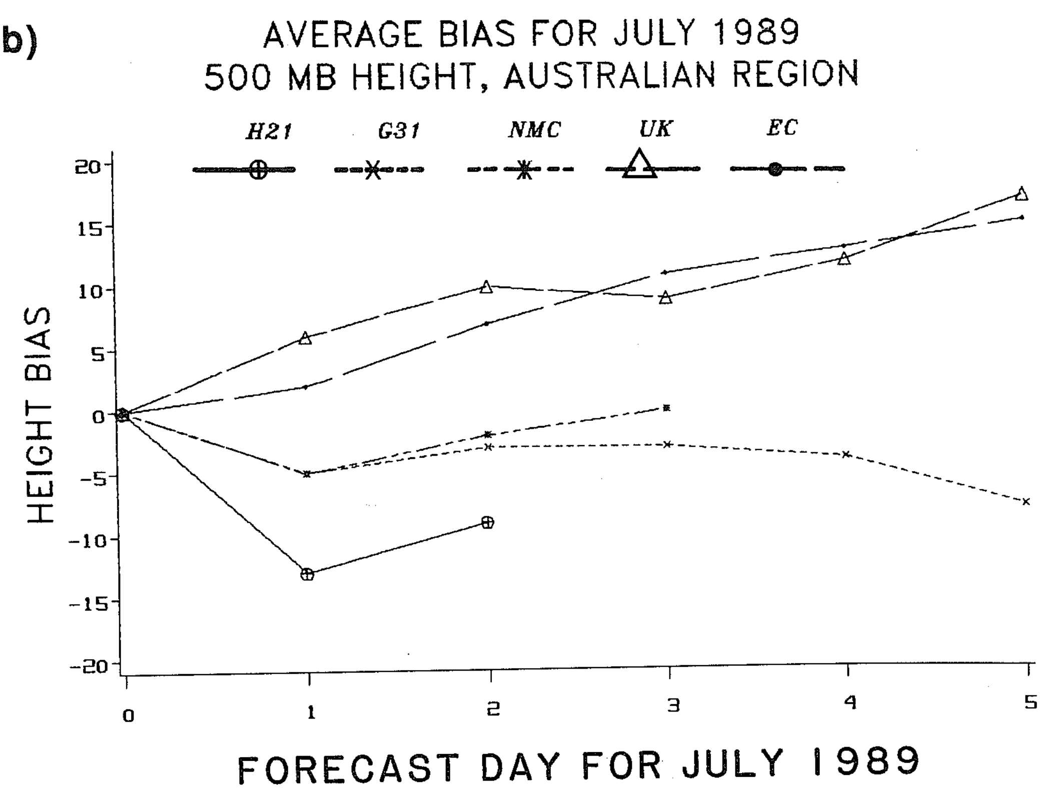


FIGURE 15
(a) The time mean RMS error in 500 mb geopotential height prediction in the Australian Region.
(b) As in (a) but for Bias

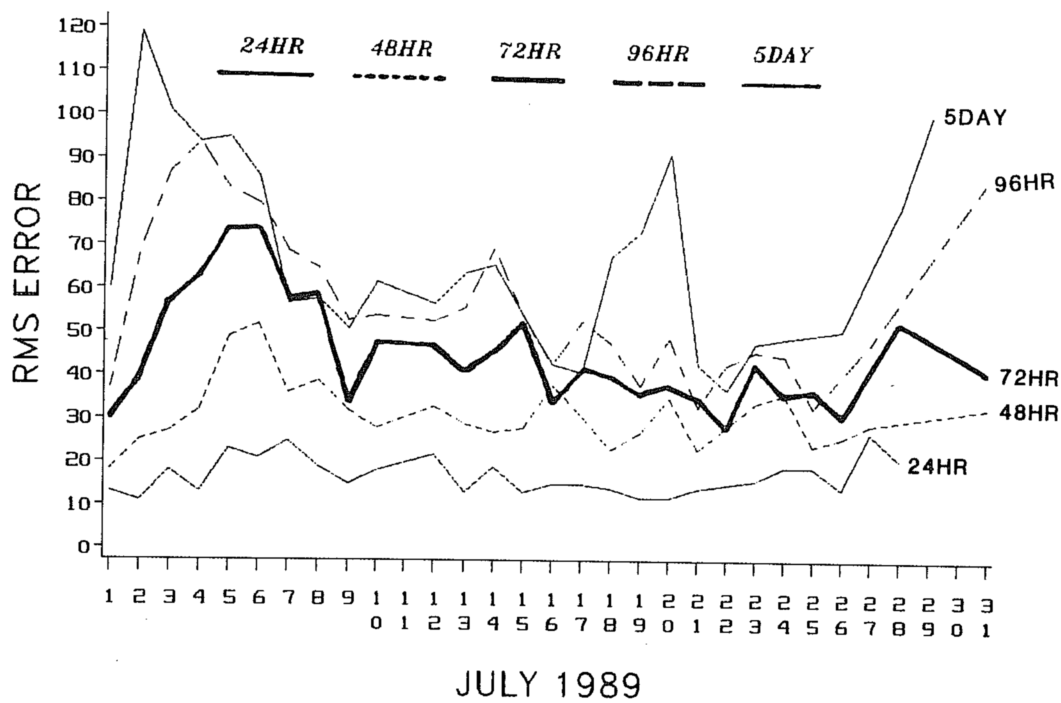
The variability in the ECMWF and BMRC predictions is shown in Figures 16 (a) and (b) respectively for the regional 500 mb geopotential height verifications. Prediction to days 1 and 2 is seen to be reasonably consistent over the month in each of the systems; at days 3,4 and 5 there is substantial variability in the day to day performance. In both systems the 5 day prediction from around July 5 and 20 was rather unsatisfactory; the period from July 5 to 9 saw the evolution of an intense cut-off low pressure system in the Tasman sea while the period from 20 - 24 saw the transformation of a deep low in the Australian Bight to a weakening trough over the continent and redevelopment over the Tasman sea of a cut-off low. These two synoptic regimes in which cut-off low pressure systems were evolving towards the end of the prediction period were poorly predicted.

6. SUMMARY

The BMRC global assimilation and prediction system was implemented on July 1, 1989 semi-operationally in Melbourne following several years of intercomparison and evaluation of performance. The performance of the system has shown an improvement over the existing operational system which can be attributed both to the increased resolution and to the extension of the domain to the globe. The hemispheric system has been shown to have a systematic cold bias in the southern hemisphere winter arising from the constraints of hemispheric geometry. The overall performance of the global BMRC medium range prediction is seen to be influenced by systematic errors common to many models. The data base available for these first studies of the global system has been inferior to those used at other centres; in particular for most of July the cloud drift winds in the northern hemisphere were unavailable and satellite soundings have been available only at 500 km horizontal resolution.

In comparison with global products from other centres available on the GTS, the BMRC global system is comparable in performance to the results obtained with the UKMO and NMC systems in the Australian region for July although the most satisfactory predictions are produced at ECMWF. Over the southern hemisphere the two global systems compared, namely BMRC and NMC, showed similar performance although the higher resolution NMC system was the more satisfactory. The BMRC predictions in the northern hemisphere are clearly less satisfactory than those available from NMC. The overall performance of the BMRC system in the northern hemisphere both with respect to analysis and prediction is a subject of particular attention at present. It should of course be stressed that the BMRC system at a resolution of R31/L9 is operating at a considerably lower resolution than that of the other global centres with which it has been compared.

a) RMS ERROR FOR ECMW JULY 1989



b) RMS ERROR FOR GASP JULY 1989

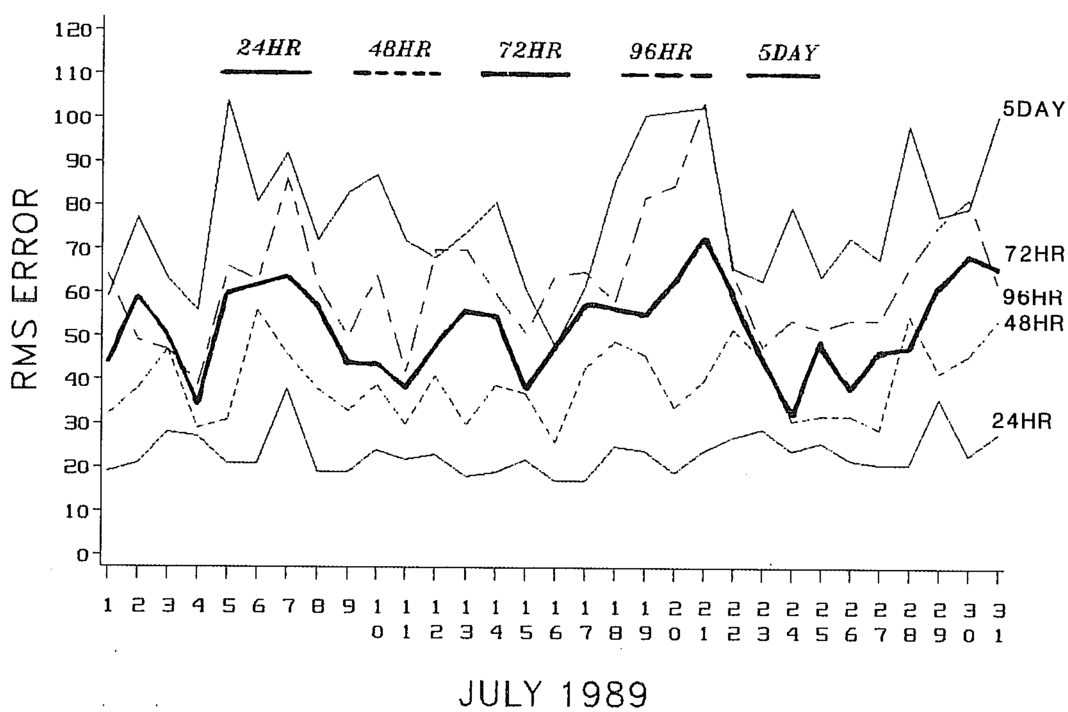


FIGURE 16

(a) Daily variability in the ECMWF 500 mb height prediction verification is shown for the Australian region from days 1 to 5.

(b) As in (a) but for the BMRC system

The BMRC global assimilation and prediction system has been initially implemented on the Bureau of Meteorology ETA10-P supercomputer. While the global numerical system has produced satisfactory results, the system has for logistical reasons only been run on the ETA10-P in parallel to the existing hemispheric operational system which is implemented on a Fujitsu M-200 computer. The ETA10-P is to be replaced by a CRAY XMP-14 in early 1990 and it is planned that with this installation the global system will become fully operational.

Future developments of the BMRC global assimilation and prediction will include increased resolution with immediate plans to assess the impact of 16 levels in the vertical at a horizontal resolution of rhomboidal wave number 45. A major upgrade to the analysis scheme ,currently being tested, is a multi-variate three dimensional statistical interpolation scheme in the sigma, Gaussian grid space of the spectral model. Improvements in quality control of the analysis are anticipated from this new analysis. A marked potential deficiency in the current BMRC system is the use of satellite temperature sounding retrievals at a resolution of only 500 km; the unequivocal impact of satellite soundings on analysis and prediction in the southern hemisphere suggests strongly that higher resolution soundings would be advantageous. In current studies we are assessing the impact of higher resolution retrievals utilising 250 km soundings such as routinely used by NMC and most other global centres. We are additionally utilising high resolution retrievals produced in Melbourne.

7. ACKNOWLEDGEMENTS

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