Mausam, (1990), **41**, 2, 257-264

551.509.313 : 551.553.21 (94)

Tropical numerical weather prediction studies for the 1987 Australian summer monsoon

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सार — 1987 के आस्ट्रेलियाई मानसून के प्रमुख लक्षणों को चित्रित करने में ECMWF विश्लेषणों पूर्वानुमान प्रणाली के निष्पादन का विवेचन किया गया है। इन लक्षणों में मानसून की अवधि के लिए माध्य परिसंचरण और आरम्भ और सक्रिय/व्यवधान अवधि निहित है। समय के साथ ऊपरी स्तर विशेष रूप के मन्द करते हुए मुख्य कमी के साथ आगे के तीन दिनों तक माध्य लक्षणों की प्रागुक्ति देने के लिए यह मॉडल सफल रहा है। यह विश्लेषण, मानसून परिसंचरण के अधिकांश लक्षणों को सफलतापूर्वक चित्रित करता है। यद्यपि यह मॉडल आरम्भ को लगभग आगे के 1 दिन और तदनन्तर घटना के लगभग आगे के 2 दिन का पूर्वानुमान देने में सक्षम है तथापि इन मॉडल पूर्वानुमान की प्रवृत्ति समय के साथ-साथ निम्नस्तरी पश्चिमीय पवनों को निर्बल करने की है।

ABSTRACT. The performance of the ECMWF analysis-forecast system in depicting the main features of the 1987 Australian monsoon is described. The features include the mean circulation for the period and the onset and active/break periods of the monsoon. The model is successful in predicting the mean features up to 3 days ahead with the main deficiency being the marked weakening of the upper level divergent circulation with time. The analyses successfully depict most features of the monsoon circulation. Although the model is able to forecast onset up to about 1 day ahead and the subsequent episodes up to about 2 days ahead, there is a tendency in the model forecasts to weaken the low level westerly winds with time.

1. Introduction

Although the performance of numerical weather prediction (NWP) models in the tropics considerably lags the performance in the extra-tropics, significant progress has been made in the recent years. For example, the systematic errors of the ECMWF model in the tropics have been considerably reduced (Tiedtke *et al.* 1988) when compared to the errors in the earlier version of the model reported by Kanamitsu (1985) and Heckley (1985). A number of factors such as increased horizontal and vertical resolution and improvements in analysis have been partly responsible for this. However, the major impact on model performance in the tropics has resulted from improvements in the parameterization of cumulus convection, interactive clouds and the radiation scheme and (perhaps most importantly) through the inclusion of shallow convection in the model (Mohanty *et al.* 1985).

In the southeast Asian region the summer (summer and winter refer to southern hemisphere season) monsoon arrives in the north around November and retreats from the region around March. During December or early January a dramatic southward shift occurs in the location of the major heat source in this region accompanied by a sudden establishment of lower tropospheric westerlies between the equator and 10° S. This constitutes the onset of the Australian summer monsoon. The Australian monsoon season can last from around 10 days to 100 days (*see* Holland 1986) and is marked by active/break periods which are associated with strengthening/weakening of the low level westerly winds. A review of the Australian summer monsoon is given by McBride (1987).

During the period 10 January to 15 February 1987 an extensive observation program was carried out in the Australian region, corresponding to phase II (the major field phase) of the Australian Monsoon Experiment (AMEX, *see* Holland *et al.* 1986). AMEX was carried out by the Bureau of Meteorology Research Centre (BMRC) in collaboration with Monash University. The experiment was designed specifically to provide a research data base of sufficient resolution both to document the basic structure of weather systems in the Australian tropics during the monsoon season and to diagnose the effects of the interactions between convective and large scale flow. The period of the experiment was marked by the onset of monsoon in the Australian region followed by active and break periods. In addition, four tropical cyclones formed during the period, two of which formed within the enhanced AMEX network. Thus the two cyclones were very well observed and provided good test cases for numerical models.

A detailed study of the performance of the ECMWF analysis forecast system has been carried out for the AMEX period with particular emphasis on the Australian summer monsoon and the tropical cyclones which

* The work described was carried out while the author was on a visit at the European Center for Medium Range Weather Forecasts, Reading, England.

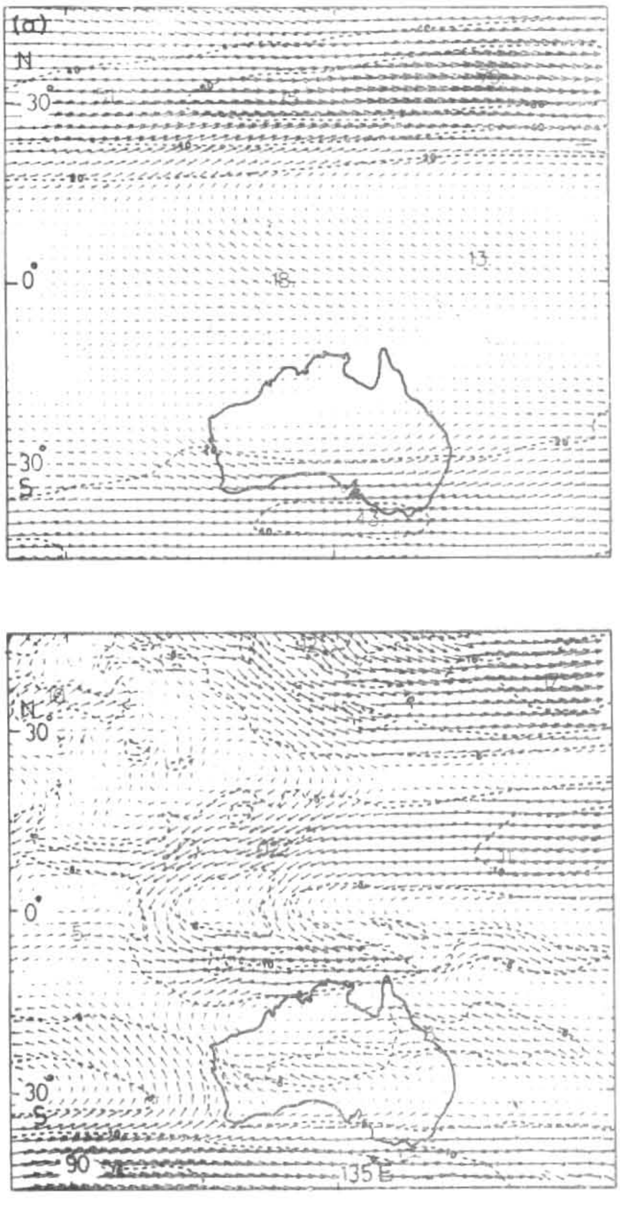

Fig. 1(a). Mean 850 hPa (bottom) and 200 hPa (top) vector wind analyses for the period 10 Jan to 15 Feb 1987

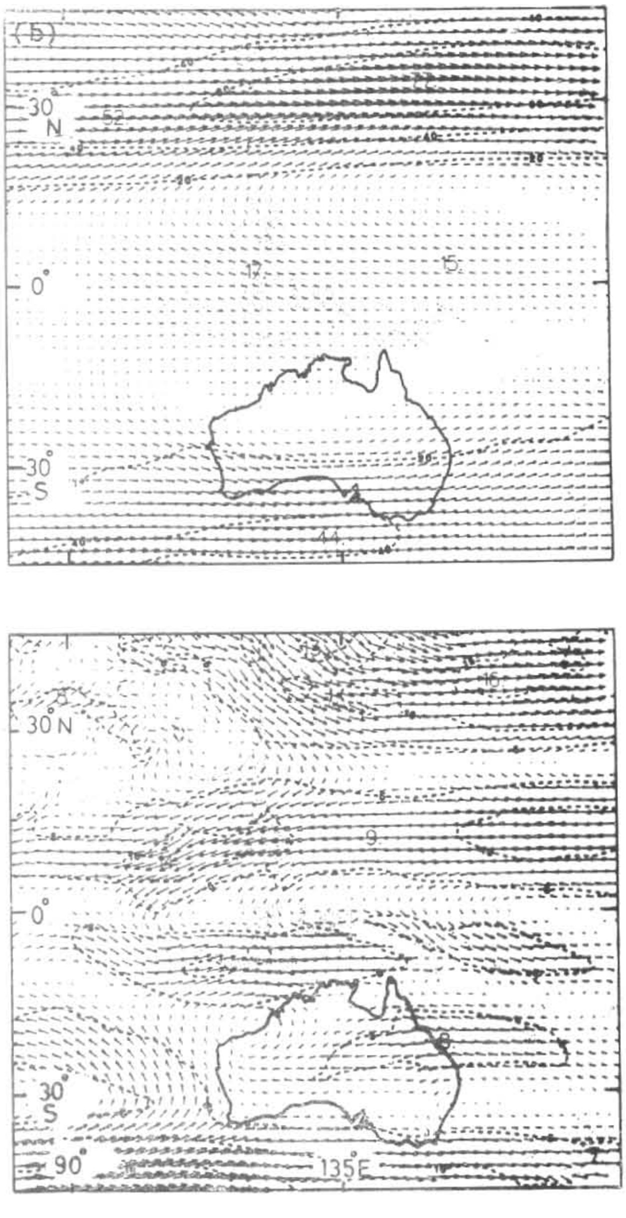

Fig. 1(b). As in Fig. 1(a) but for 48-hr forecasts

formed in the region. In this paper the performance of the system in depicting the main features of the Australian monsoon circulation during AMEX and some individual features such as the onset of the monsoon and active and break periods during the monsoon will be described. In most cases only forecasts up to 72 hours will be considered as the model skill in the tropics beyond this period falls off rapidly.

The model used in these studies is the operational (As at Feb 1987) ECMWF model which has 19 levels in the vertical and is truncated at triangular wave number 106 (T_{106}) in the horizontal. The model includes all the revised parameterizations made in May 1985. The revised parameterizations which include shallow convection, a more effective representation of deep convection, a new cloud scheme and improvements in the radiation scheme, resulted in significant improvements in the representation of the quasi-stationary flow in the tropics. Since then a gravity-wave drag formulation and improvements in the analysis scheme have been implemented which have resulted in further improvement in the performance of the analysis-forecast system.

2. Results

(a) *Mean circulation*

Fig. 1(a) shows the mean 850 hPa and 200 hPa wind analyses for the period 10 Jan to 15 Feb. 1987. The period was marked by strong low level westerly flow over and to the north of northern Australia which is typical of the Australian monsoon circulation. There is

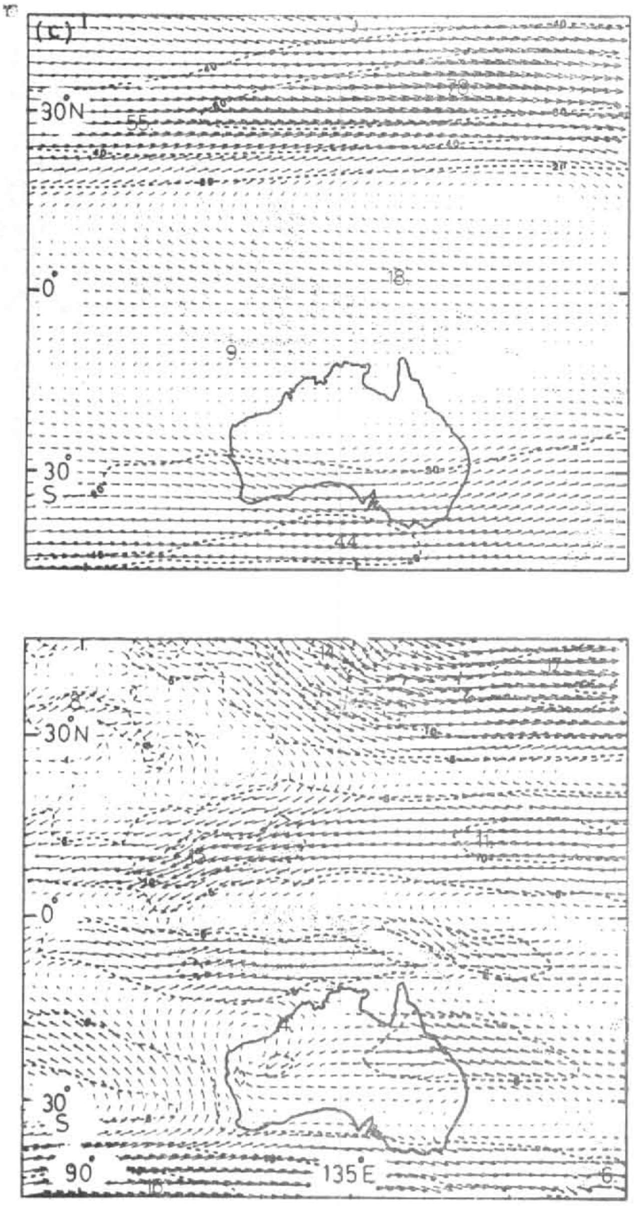

Fig. 1(c). As in Fig. 1(a) but for 72 hr forecasts

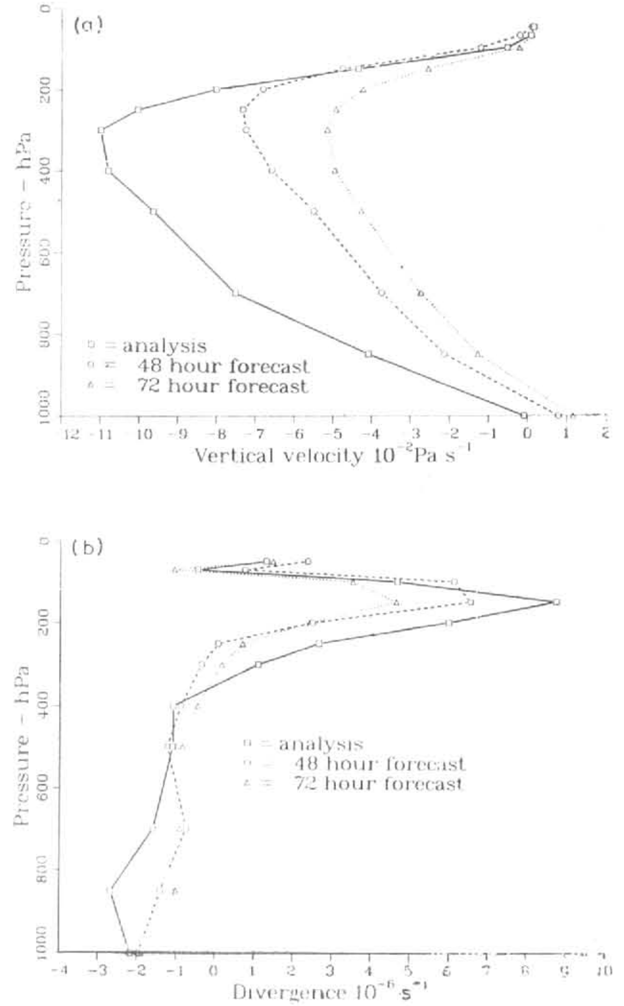

Fig. 2. Vertical sections of area mean (5°S to 15°S, 110°E to 140°E) divergence (bottom) and vertical velocity (top)

cyclonic circulation in the Gulf of Carpentaria and off the west Australian coast. Another feature of note is the strong cross-equatorial flow from the northern to southern hemisphere in the regions around 100° E and 125° E. The ECMWF analysis of the mean circulation agrees with the mean obtained from the Australian Bureau of Meteorology's tropical analysis scheme (not shown). The agreement between the two independent analyses with respect to the main features of the monsoon circulation is very encouraging. Figs. 1 (b) and 1 (c) show the 48-hour and 72-hour forecasts verifying for the analysis period shown in Fig. 1(a). The low level westerly flow to the north of Australia is well handled at 48 and 72 hours although the westerlies are weaker than analysed and the underestimate increases with time. The cyclonic circulations in the Gulf of Carpentaria and off western Australia are well forecast at 48 hours. The circulation in the gulf has weakened by day 3 and is located too far to the east over western Australia. The cross-equatorial flow at both 48 hours and 72 hours, although occurring at the correct locations, is much weaker than the analysed flow. The vertical sections for the analyses and 48 and 72-hr forecasts are shown in Fig. 2.

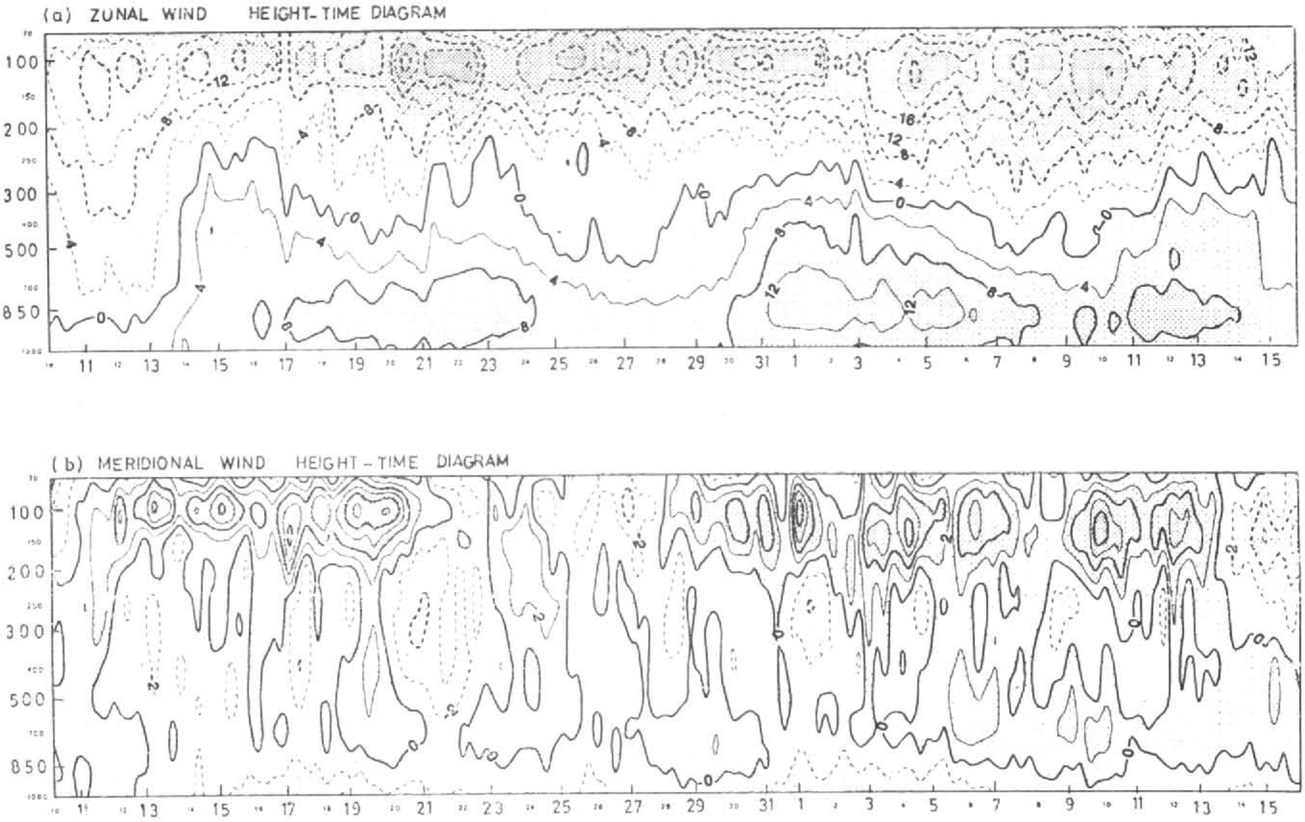

Fig. 3. Vertical sections of area mean (5°S to 15°S, 110°E to 140°E) zonal and meridional winds as analysed at ECMWF as a function of time

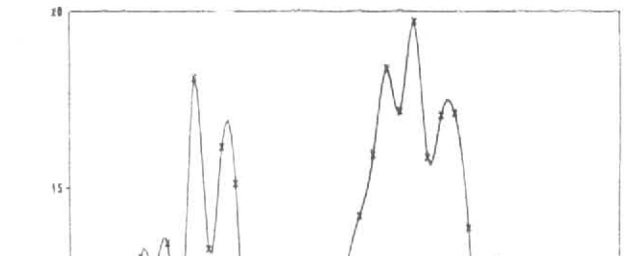

Fig. 4. Area averaged (5°S to 15°S, 110°E to 140°E) 24-hr forecast precipitation as a function of time

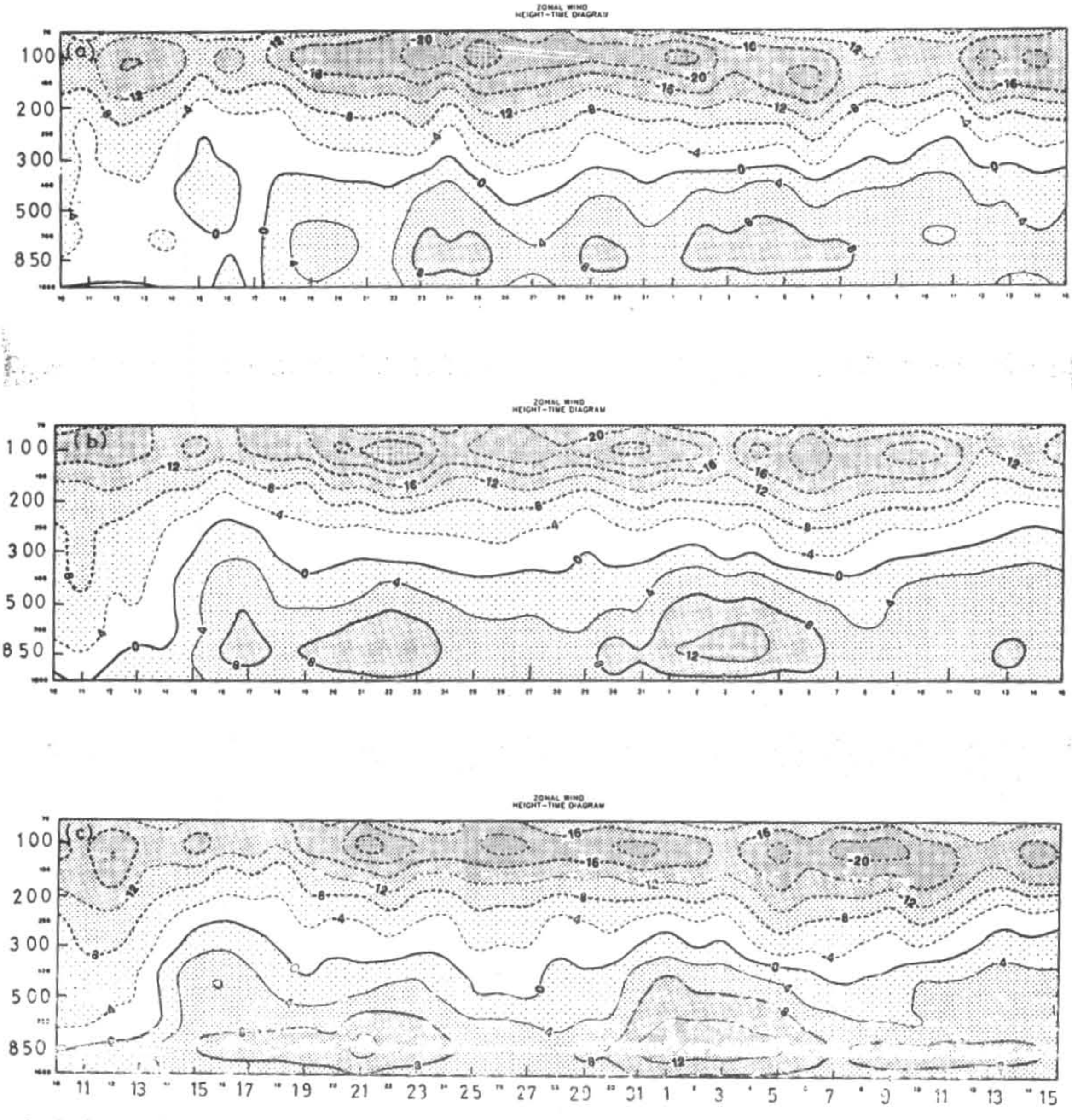

Fig. 5. Vertical sections of area mean (5° S to 15° S, 110° E to 140° E) zonal wind for 24-hr (bottom), 48-hr (middle) and 120-hr (top) forecasts as a function of time

(b) *Australian summer monsoon — Onset and active/ break periods*

In this section the ability of the ECMWF analysis-forecast system in handling some of the aspects of the Australian summer monsoon will be described. The onset of the monsoon during AMEX as indicated by the low level winds occurred on 14 Jan with a weak break from around 25 January to 29 January followed by a further active break (*see* Gunn *et al.* 1989). Fig. 3 shows the vertical section of the area mean (5° S to 15° S, 110° E to 140° E) zonal and meridional winds as analysed at ECMWF as a function of time. The time frequency of the analyses is six hours. Apart from differences in the intensities of the low level winds, there is good agreement with the height-time sections obtained from the Australian tropical analyses. The ECMWF analyses, in agreement with the Australian analyses also indicate monsoon onset occurring around 14 Jan with a weak break from 25 to 30 January followed by a mainly active period. Fig. 5 shows similar height-time sections for the 24, 48 and 120-hour forecast respectively.

As with the wind field the main features of geopotential height field (not shown) are the good consistency between the 48 and 72-hour forecasts and the good agreement between the analyses and forecasts. The main error at 1000 hPa is the underestimation of the height over north and northwest regions of Australia. The deficiency is related to the underestimation by the model of the intensity of four tropical cyclones which occurred in this region.

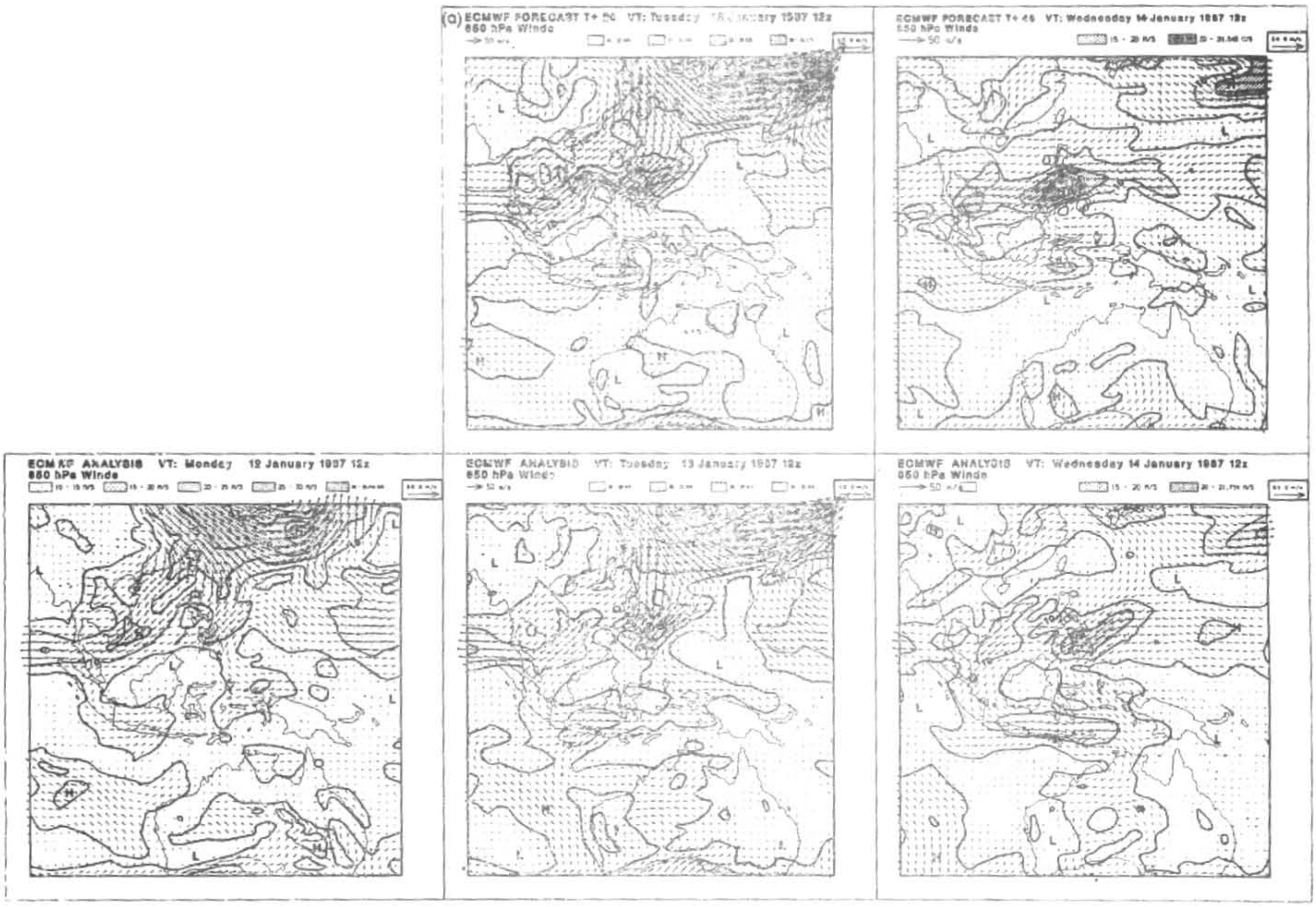

Fig. 6(a). 24-hr and 48-hr, 850 hPa vector wind forecasts from 1200 GMT of 12 to 14 Jan 1987 together with starting and verifying analyses

The divergent component of the wind forms an important part of the tropical circulation. Comparison of charts similar to those shown in Fig. 1 shows that, although the 48 hour and 72-hour forecasts for the velocity potential are consistent with each other, the agreement with analysis is not as good as for the stream function. The forecasts for the latter field show good agreement with the verifying analyses. The forecasts for the upper level divergent circulation show a marked weakening with time. The weakening trend in the divergence and vertical velocity can be seen in the vertical sections of the area means (5° S to 15° S, 110° E to 140° E) of these fields shown in Fig. 2. Note the marked weakening for both fields in the upper troposphere. This systematic weakening of the upper level divergent circulation is a consistent feature of the ECMWF analysis-forecast system which has not been altered by significant improvements in various components of the system. The error is probably related to the systematic underestimation of forecasts respectively. The 24-hour forecasts show an impressive skill in predicting most of the features of the monsoon present in the analyses. Particularly impressive is the accurate prediction of the onset date and the active/break periods as evident from the strengthening/weakening of the low level westerlies. The 48-hour forecast does not predict the onset date which in fact only shows up in the 48-hour forecast valid for 15 Jan. However, the 48-hour forecasts provide a reasonable guidance for the following break and active periods. The 120-hour forecasts show little skill in handling any of the features of the monsoon.

The onset of the Australian monsoon is accompanied by a rapid increase in convective activity over the northern regions of Australia. Fig. 4 shows the 24-hour forecast area averaged precipitation (5° to 15° S, 110° E to 140° E) as a function of time from 10 Jan to 15 Feb 1987. Although the intensity of precipitation is difficult to verify, the model displays an impressive capability in forecasting the rapid increase in precipitation with the onset of monsoon followed by a decrease in the break period and then increased precipitation in the following active period. The precipitation in the latter period of February is too low and is possibly related to the failure of the model in handling tropical cyclone *Jason* which formed in the Gulf of Carpentaria.

Closer inspection of Figs. 3 and 5 around 14 January indicates that the model fails to capture the monsoon onset until some low level westerlies are established in the initial conditions. This is better illustrated in

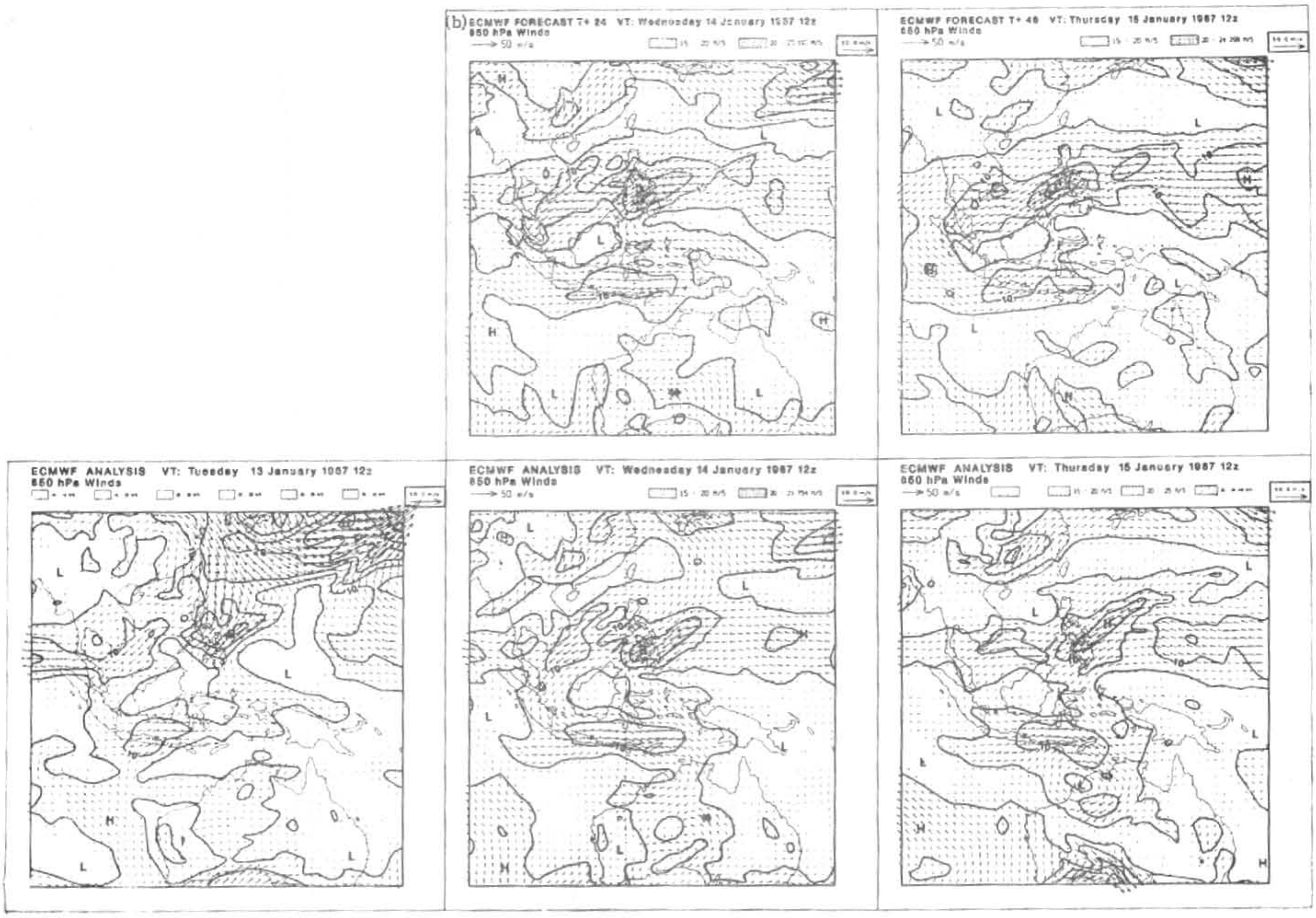

Fig. 6(b). As in Fig. 6(a) but for forecasts from 1200 GMT of 13 to 15 January

Figs. 6(a) to 6(c) which show the 24 and 48-hour forecasts for the 850 hPa wind field starting from 12 Jan to 14 Jan together with the starting and verifying analyses. The main feature to note in the analyses from 12 Jan to 16 Jan is the marked southward shift in low level westerlies around 14 Jan together with an increase in the westerly winds in the region over and to the north of northern Australia. The 24 and 48-hour forecasts from 12 Jan (Fig. 6 a) fail to capture any of these changes. The 24-hour forecast from 13 Jan (Fig. 6 b) predicts the strengthening of the westerlies (and therefore, the monsoon onset); however the 48-hour forecast fails to retain the strong westerlies. Both the 24 and 48-hour forecasts from 14 Jan which start with strong westerlies in the initial conditions provide good forecasts of the winds although the strong cross-equatorial flow near 125° E is poorly predicted. However, the above results indicate the inability of the model to retain low level westerlies unless they are well established initially. The reason for this is not clear and is probably linked to the marked reduction in the convective activity in the model with time which was noted earlier.

As was noted earlier, there was a weak break in the monsoon from around 25 Jan to 29 Jan which was marked by a weakening of the low level westerlies to the north of northern Australia and subsequent strengthening of the winds around 30 Jan. Both these features were well depicted by the analyses. The 24-hour and 48-hour forecasts also reflect these changes in the circulation. Given that the contrast in the 850 hPa winds for the two periods is quite marked, it is encouraging that the model is able to simulate some of these features.

3. Conclusion

The main aim of the study presented here is to assess the performance of the ECMWF analysis-forecast system in depicting the main features of the tropical circulation in the Australian region for the period 10 January to 15 February 1987 during which the Australian Monsoon Experiment was conducted. The features include the onset of the Australian summer monsoon and the active and break periods during the monsoon.

The model is successful in predicting the mean features during the period up to 3 days ahead. The major deficiency is a marked weakening of the upper level divergent circulation which appears to be related to the marked weakening in convective activity with time and underestimation of the outgoing longwave radiation in the

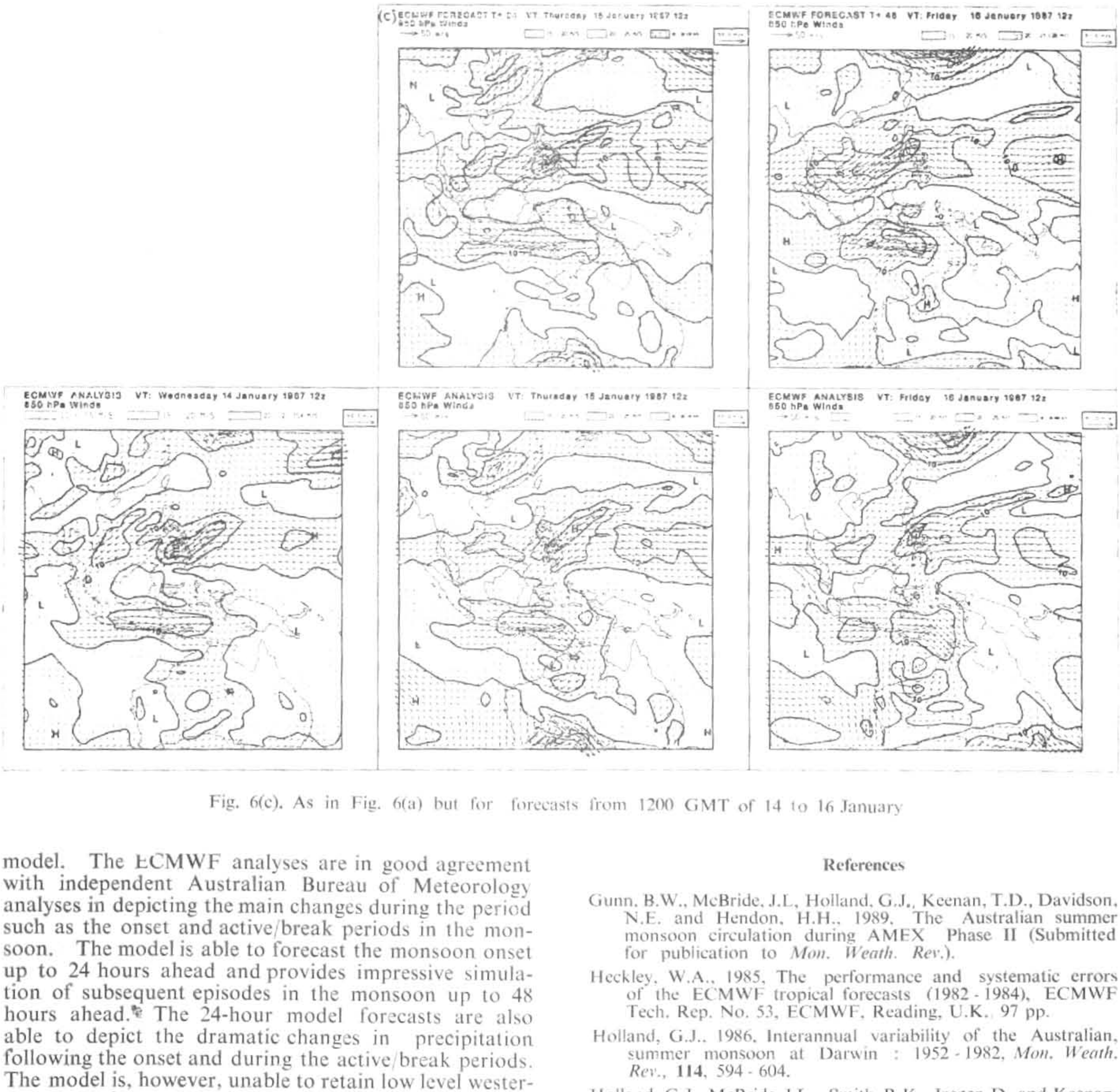

Fig. 6(c). As in Fig. 6(a) but for forecasts from 1200 GMT of 14 to 16 January

model. The ECMWF analyses are in good agreement with independent Australian Bureau of Meteorology analyses in depicting the main changes during the period such as the onset and active/break periods in the monsoon. The model is able to forecast the monsoon onset up to 24 hours ahead and provides impressive simulation of subsequent episodes in the monsoon up to 48 hours ahead. The 24-hour model forecasts are also able to depict the dramatic changes in precipitation following the onset and during the active/break periods. The model is, however, unable to retain low level westerlies beyond 36 - 48 hours unless these westerlies are well established in the initial stage. It should be pointed out that this deficiency is not a feature of the ECMWF model alone; a very similar behaviour is also seen in the BMRC global spectral model. The reason for this problem is not clear and needs further investigation. One possible reason could be the marked reduction in convective activity with time or convection in the model occurring at incorrect locations. These convection related factors are currently being investigated.

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