THE PERFORMANCE OF OBSERVING AND FORECASTING SYSTEMS IN THE TROPICS

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1. INTRODUCTION

This paper is not meant to give a comprehensive review of the tropical observing systems and the performance of numerical models in the tropics. We will address some of the data problems which, according to the ECMWF data monitoring system, have persisted over several years and others which were introduced recently. The model performance will be reviewed by looking at the impact of recent changes and at the capability of global models in predicting tropical storms.

2. DATA DEFICIENCIES AND IMPACT OF BAD DATA

2.1 Data availability

The availability of conventional observational data is limited and insufficient in the tropical belt compared with continental mid-latitude areas. Contributing factors are the dominance of the oceans, but also inadequate telecommunications facilities for data transmission from the observing site to the national meteorological centres for injection onto the Global Telecommunication System (GTS) of the WMO.

Tables 1 and 2 give a summary of the reception rates for height and wind observations from radiosonde and pilot wind stations. Recent improvements in the availability of wind data from aircrafts (AIREP) are highlighted in Fig. 1 by the shading.

Noting the scarcity of in situ observations in the tropics, the importance of satellite sounding and wind vector data becomes obvious. Some of the problems related to the quality of cloud motion wind observations (SATOB) are discussed in the following chapter.

Before looking at the quality of the wind observations in the free atmosphere recent problems with surface wind data from moored buoys in the tropical Pacific will be discussed.

2.2 TOGA moorings

The moored buoys in the TOGA programme are a typical example of data deficiencies over the tropical oceans: in June 1989 ECMWF data monitoring statistics revealed large differences between winds reported by buoys operated by the Pacific Marine Environment Laboratory (NOAA/PMEL) and the ECMWF first-guess. In fact, the buoys reported constantly westerly winds in an area where easterly trade winds prevail. This resulted in a large scale impact on the analysed and forecast flow pattern. There was a 180 degree wind direction error for all these buoys which occurred when they were first encoded for injection into the GTS. These observations had to be excluded from the

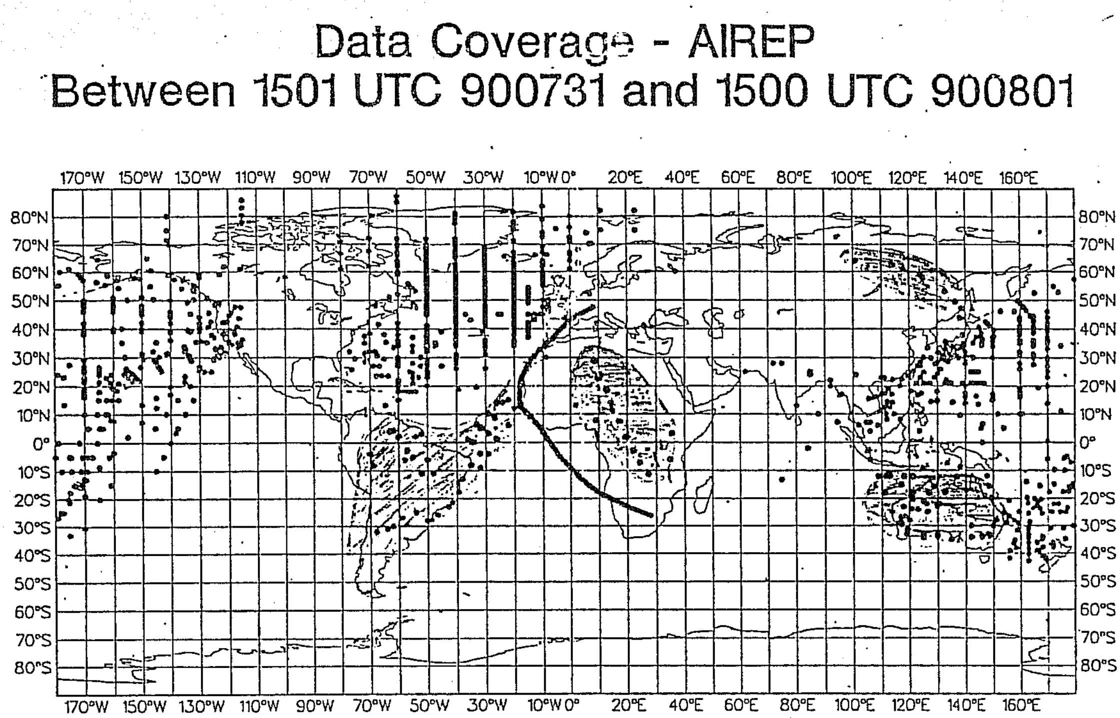


Fig. 1: Coverage of aircraft data for one 24 hr period 31 July 1990, 1501 UTC, to 1 August 1990, 1500 UTC, shaded areas highlight regions of recently enhanced coverage

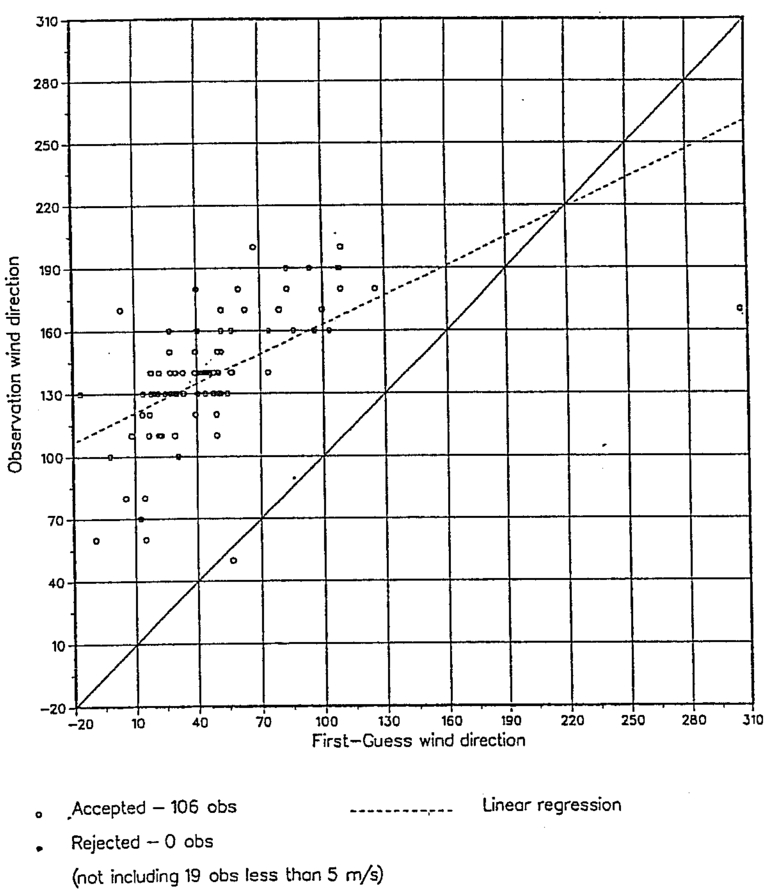


Fig. 2: Comparison of observed and predicted wind directions (ECMWF 6-hr forecast, first-guess) for moored buoy 52302 in the tropical Pacific during March 1990

L E V E L	00 UTC		12 UTC	
	Total	%	Total	%
1000	1,722	62	1,682	57
850	1,870	67	1,896	64
500	1,884	68	1,909	64
250	1,813	65	1,793	60
100	1,565	56	1,579	53
50	1,087	39	914	31
10	174	6	180	6

Table 1: Availability of height reports in the tropical belt 20N - 20S, May 1990. Total gives the number of observations received for each standard pressure level, % is with respect to the total number of reports expected from all active stations.

L E V E L	00 UTC		12 UTC	
	Total	%	Total	%
1000	665	28	772	28
850	1,427	60	1,622	59
500	1,461	61	1,752	64
250	1,410	59	1,632	59
100	1,123	47	1,388	50
50	750	31	748	27
10	139	6	116	4

Table 2: Availability of wind reports in the tropical belt 20N - 20S, May 1990. Total gives the number of observations received for each standard pressure level, % is with respect to the total number of reports expected from all active stations.

ECMWF analysis until the problem was corrected in July 1989. However, in 1990 two new buoys were deployed, exhibiting a 90 degree direction bias when the observations became available over the GTS and were evaluated by the ECMWF monitoring system. An example of one buoy in the western tropical Pacific is given in Fig. 2. Wind observation errors in the tropics especially at isolated observation points have a detrimental impact on the wind analysis. These errors have the potential to develop and will, on occasions, adversely affect the predicted flow pattern in mid-latitudes.

2.3 Cloud motion wind data

The cloud motion vector winds (SATOB) provide the backbone for any analysis of the atmospheric circulation in the tropics. Soundings from radiosonde stations are few and far between in the tropical belt and the soundings from the polar orbiting satellites are of limited value only. Data volumes for satellite winds in the tropics are three times those for TEMP and AIREP data. Reliable wind data are required to perform good quality analyses in the tropics. Recently, Hollingsworth et al. (1991) studied the quality of the upper level wind data and provided corroborating evidence of the well known fact that, while the satellite wind data are the primary data source for the numerical wind analysis in the tropics, they are, in particular in the high speed category, underestimating the wind speed. TEMP (PILOT) and AIREP wind observations are independent measurements and generally fulfil the high quality requirements (Baede et al., 1987). This is reflected in the lower observation error ascribed to the radiosonde and aircraft data in the ECMWF mass and wind analysis (Shaw et al., 1987).

Figs. 3 and 4 give the evolution of the speed bias for upper level satellite winds from the three geostationary satellites Meteosat, GOES and Himawari compared with the ECMWF first-guess fields. Significant improvements can be detected over the recent years, in particular for the Meteosat winds, but the negative bias remains a cause for concern.

3. MODEL PERFORMANCE IN THE TROPICS

Fig. 5 shows the increase in the skill of ECMWF wind forecasts in the tropics at the 200 hPa level. In particular, model changes implemented in 1989 and 1990 contributed to a large extent towards an overall improvement in skill. These changes were related to the use of wind data in the analysis including more stringent quality control checks on satellite wind data and wind observations from aircrafts, but also to modifications in the parametrization of physical processes, such as improved surface fluxes at low wind speeds over sea and a better formulation of non-precipitating convective clouds.

The impact of these changes is reflected in more detail in a better description and maintenance of the monsoon flow over the Indian subcontinent.

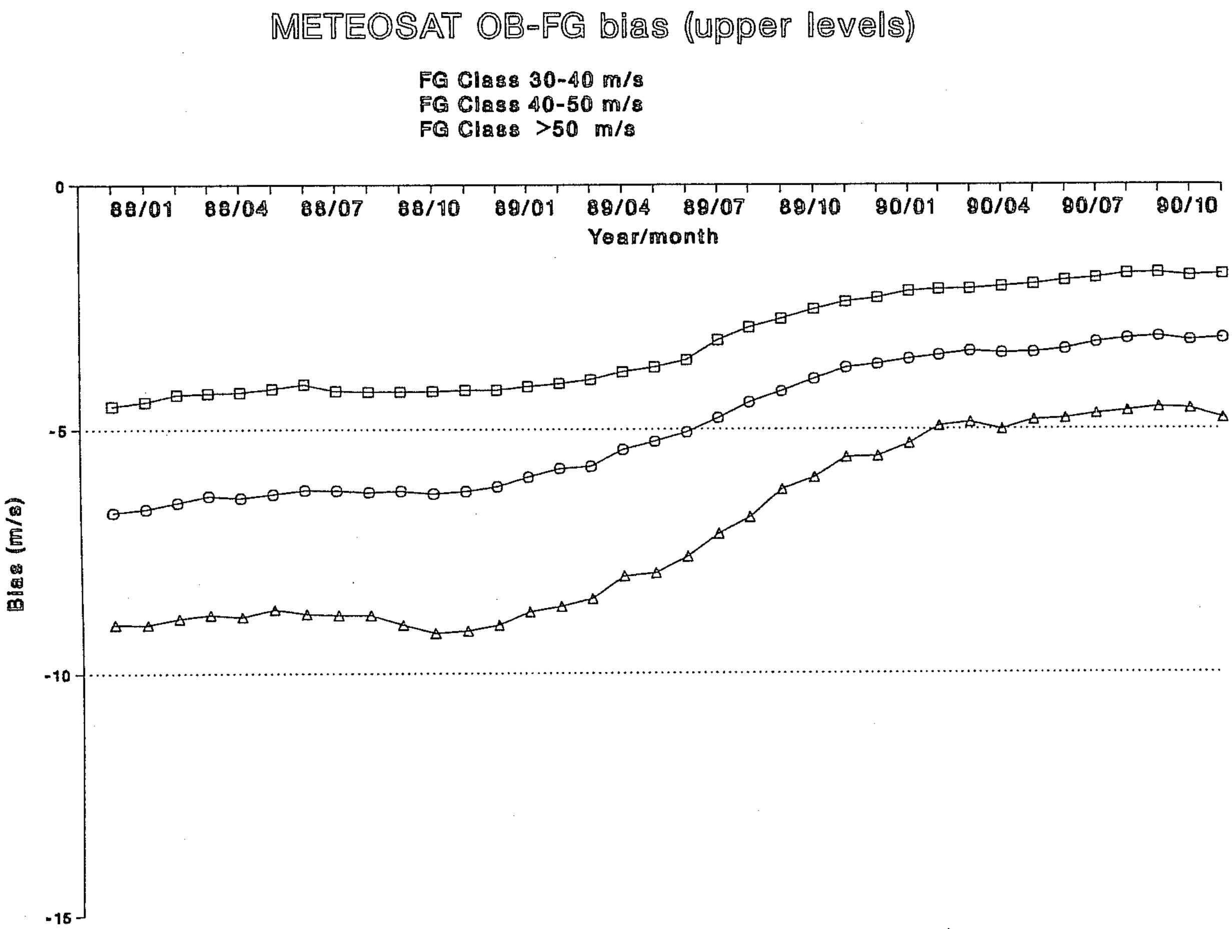
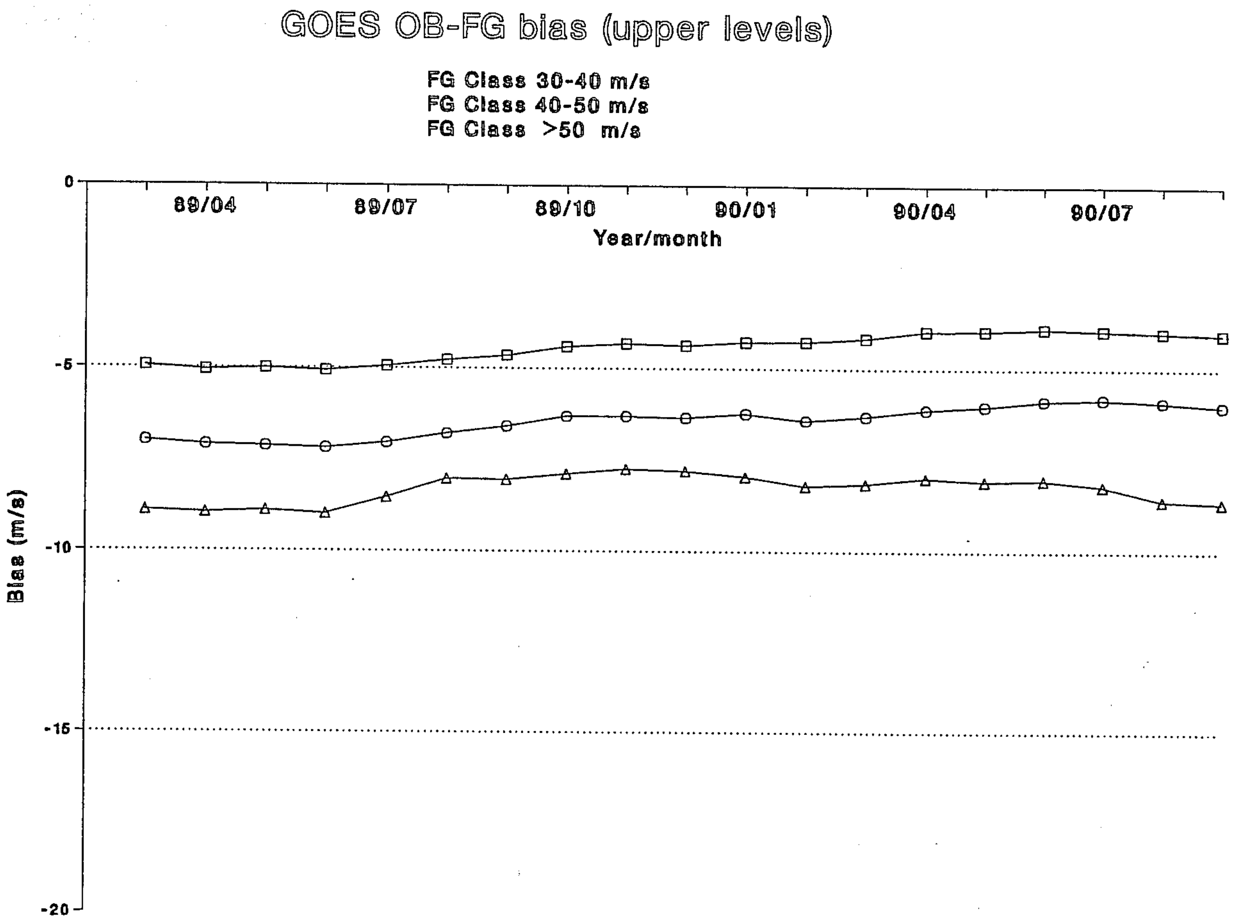


Fig. 3: Evolution of the speed bias for Meteosat cloud motion winds in three speed classes, based on comparison with ECMWF first-guess. Period is 1988 to October 1990



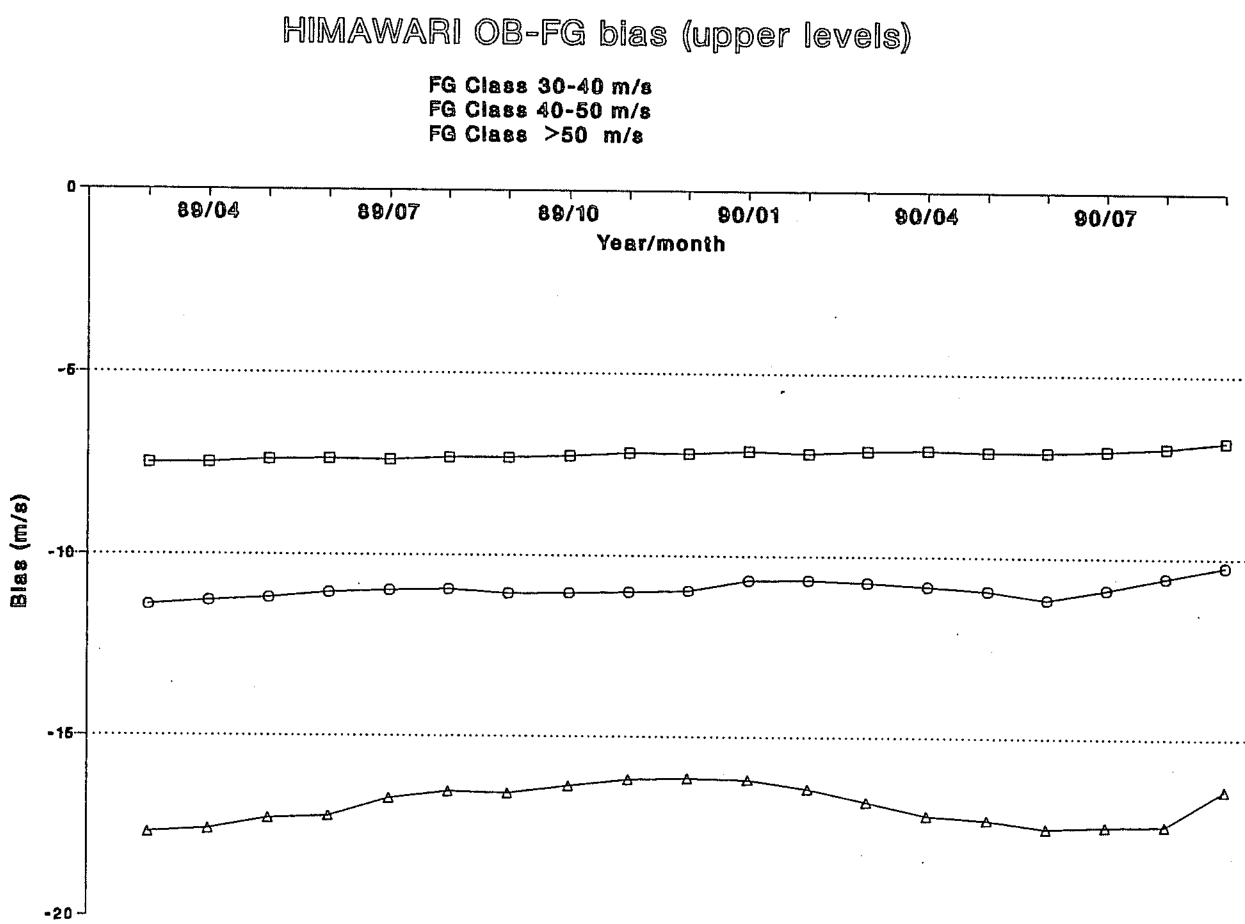


Fig. 4: As Fig. 7 but for GOES winds (top) and Himawari winds (bottom), period is 1989 to September 1990

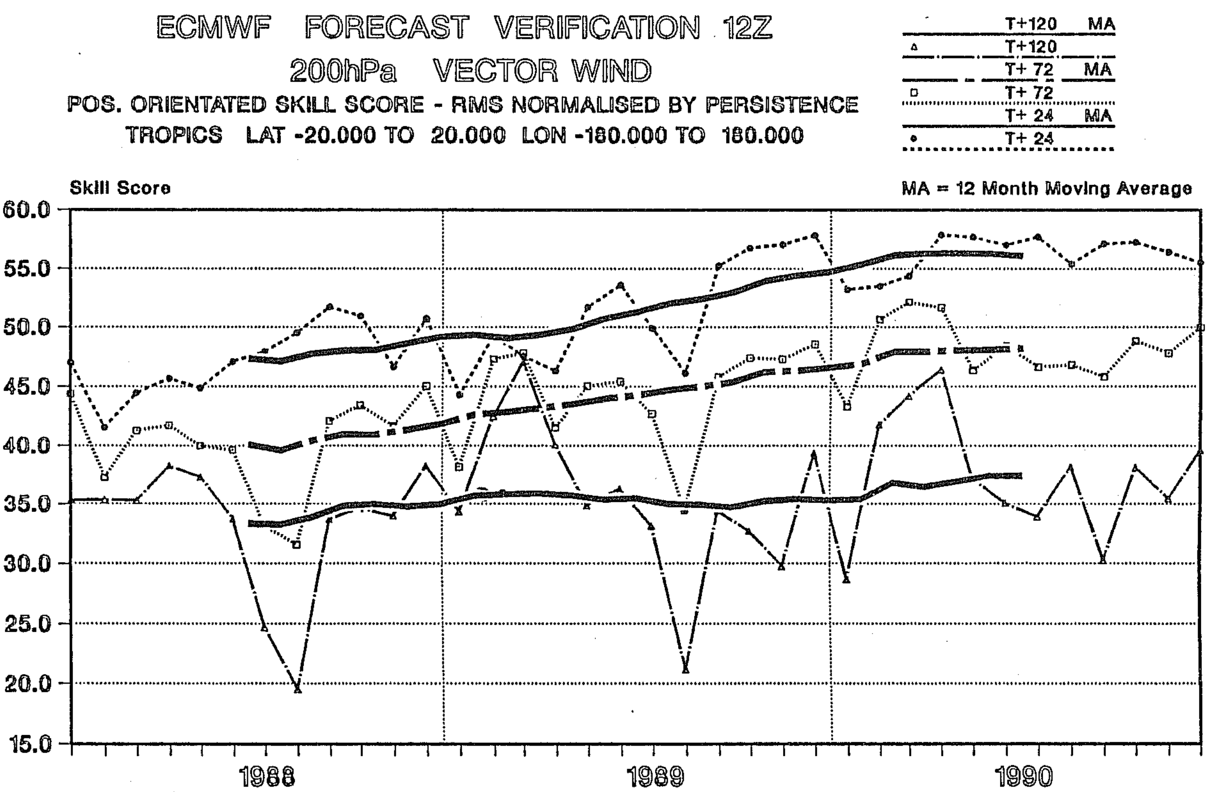


Fig. 5: Skill of ECMWF wind forecasts at 200 hPa based on RMS errors normalised by persistence.

3.1 Indian monsoon flow

Fig. 6 shows the analysed 850 hPa wind field and isotachs over the Indian ocean averaged over the period 1.7.-31.7.90 valid at 12 UTC, together with the corresponding 72-hour forecast and the mean error field (Fig. 7 top panel) using the analysed flow as the ground truth.

The Somali jet penetration across the Arabian Sea towards India and the monsoon trough towards the east of the Continent are well captured in the analysis. Only a minor proportion of the strength of the Somali jet is lost in the 3-day forecast, while the monsoon trough is clearly weakened. The error is well reflected in the error field. However, the previously overestimated extension of the monsoon flow into the northern part of the Indian subcontinent (Datta et al., 1986) has been significantly reduced (c.f. Fig. 7 bottom panel, which shows the error in the summer of 1989), giving a climatologically more consistent precipitation pattern.

In the upper troposphere, the deceleration of the easterly flow over southern India still persists.

3.2 Indian monsoon precipitation

Results from a recent evaluation of the precipitation over India are displayed in Fig. 8. The mean forecast 24-hour precipitation in July 1990 is plotted as a shaded field. The mean observed rain amounts are given by numbers. The mean observed precipitation has been calculated from observations of precipitation accumulated over 21 hours reported at 00 UTC, therefore approximately 13% should be added to any single value in order to get an estimate of the true 24-hour rainfall amount.

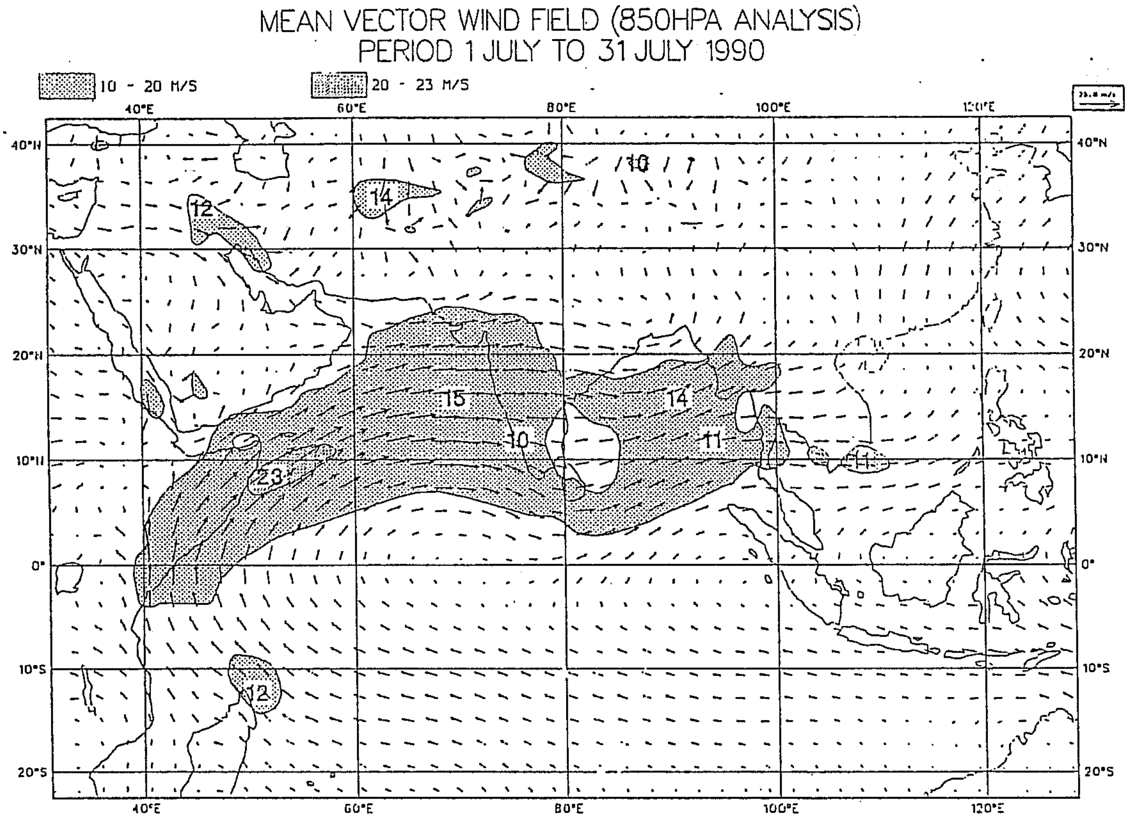
It appears that the large scale distribution of precipitation over India is reasonably represented by the model. The rain maxima along the western coast and over the north eastern parts of India are well captured, whereas the areas in the south east where only sparse rain is reported, are predicted to be mainly dry.

Datta et al. (1988) found that the model underestimates the daily mean precipitation along the Indian west coast in July, by up to 12 mm (day two forecast). The recent results suggest that the forecast error here is now smaller. This indicates a positive impact of a number of changes in the model which have been made since 1988.

The structure of the rainfall pattern remains the same for all forecast steps up to day 10 (not shown). However, after day 3 there is a marked drop in the amount of forecast precipitation and dry areas become larger at the expense of areas with small amounts of precipitation.

3.3 Tropical cyclones

In the early years of operational forecasting at ECMWF the model's capability of predicting tropical cyclones was rather limited reflecting more the probability of such features developing in certain regions over the tropical oceans rather than giving a reliable prediction of the track and timing of



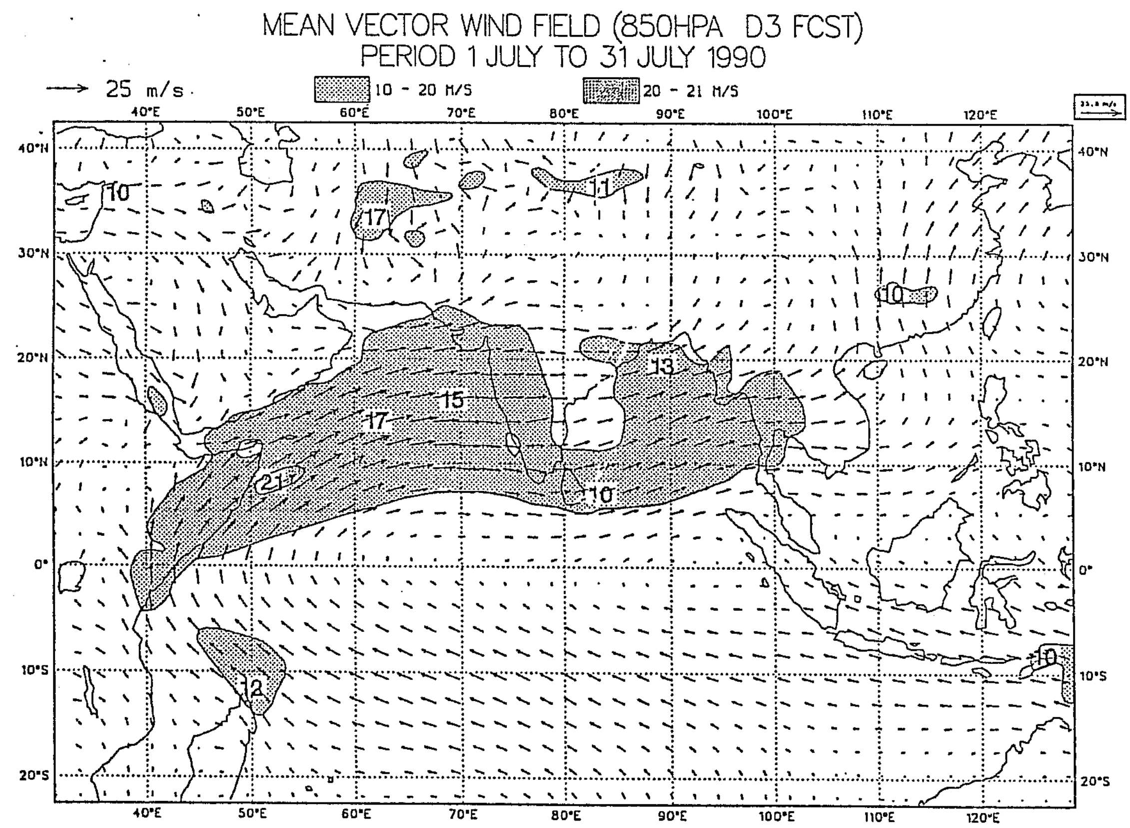


Fig. 6: Mean ECMWF vector wind field at 850 hPa in July 1990, analysed (top) and 72 hr forecast (bottom), shading level is 10 ms^{-1}

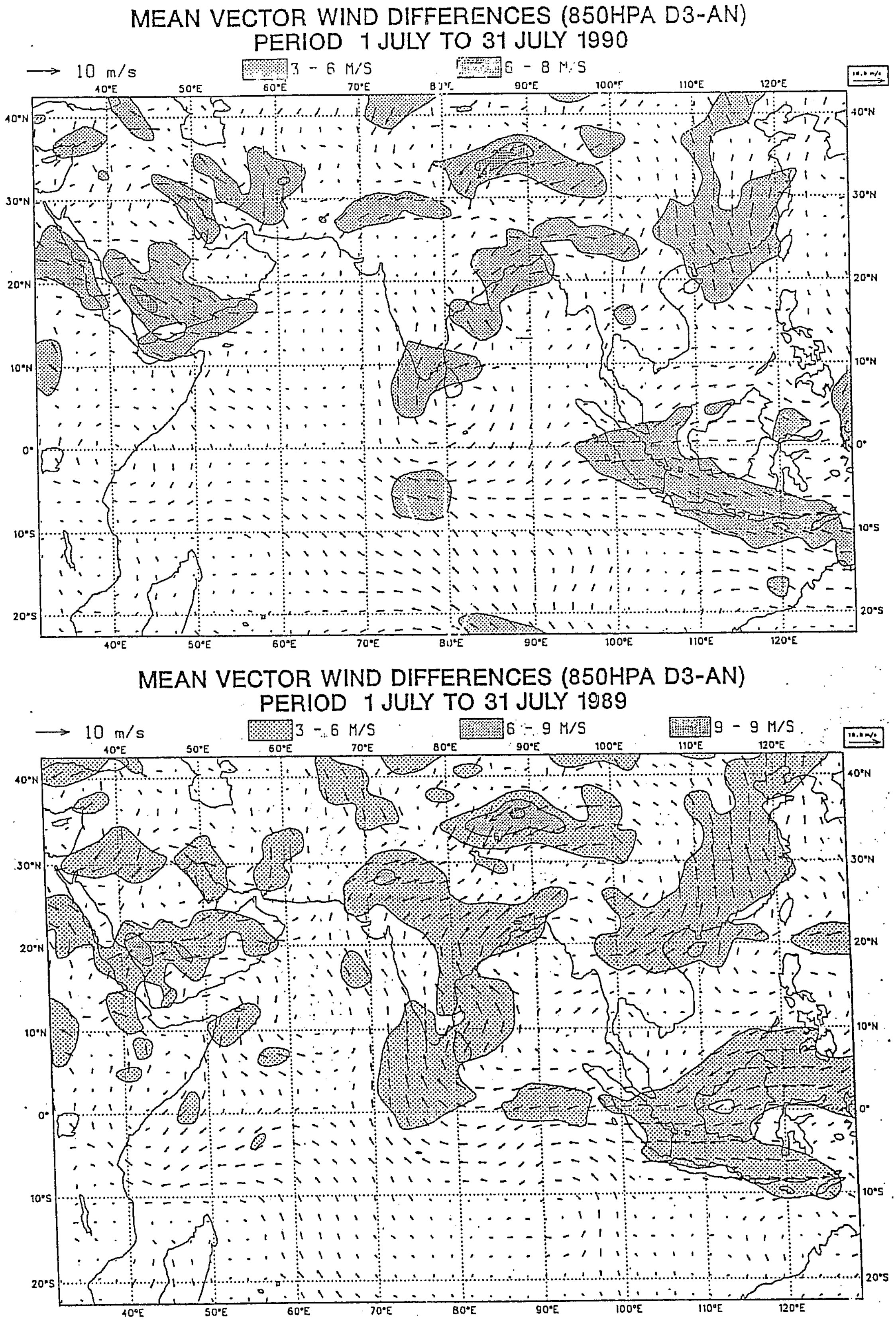


Fig. 7: Mean ECMWF vector wind difference at 850 hPa in July 1990 (top) and July 1989 (bottom) for 72 hr forecast minus analysis, shading interval is 3 ms^{-1}

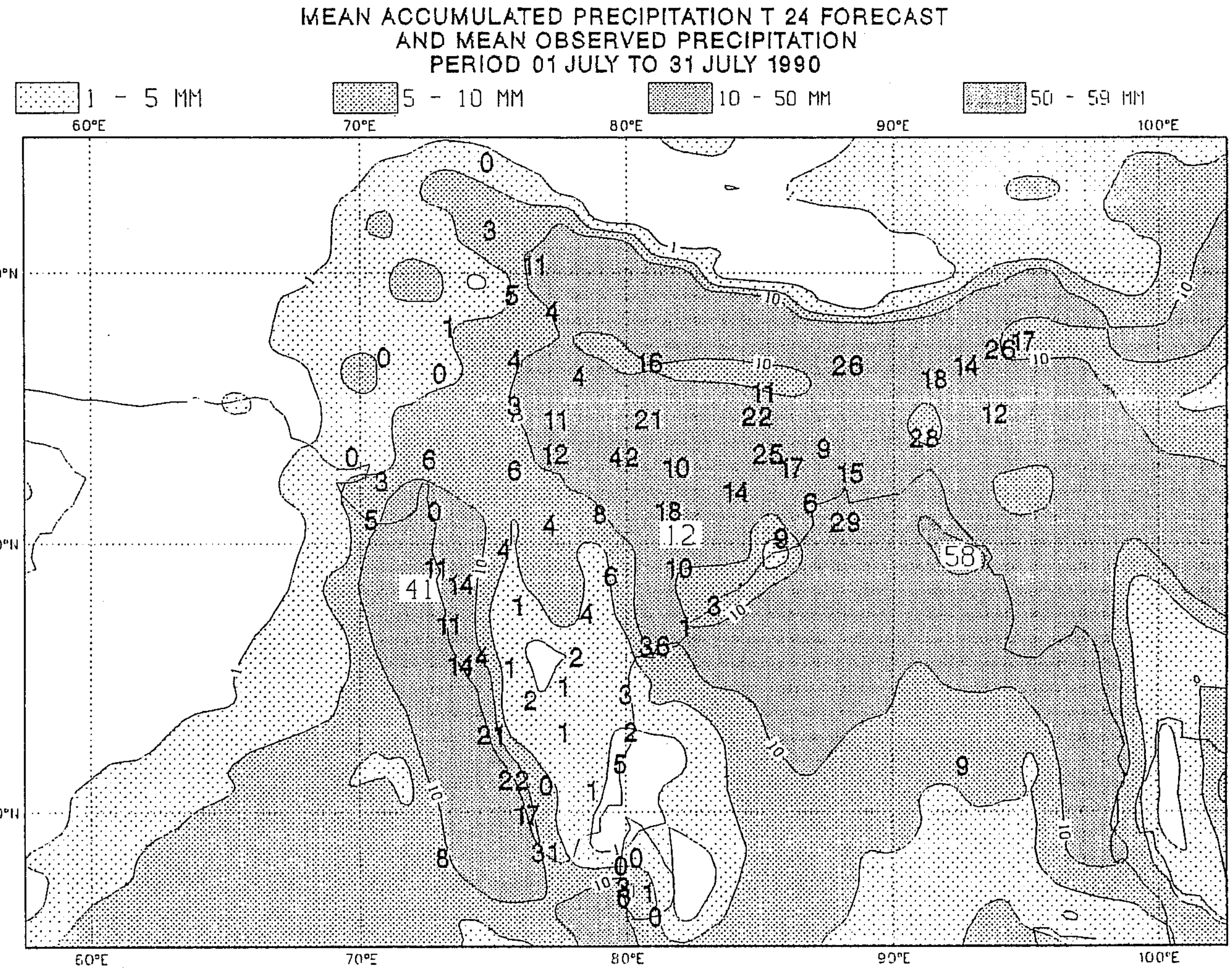


Fig. 8: Mean ECMWF precipitation forecast in mm accumulated over a 24 hr forecast range together with corresponding observations, July 1990

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3.3 Tropical cyclones

In the early years of operational forecasting at ECMWF the model's capability of predicting tropical cyclones was rather limited reflecting more the probability of such features developing in certain regions over the tropical oceans rather than giving a reliable prediction of the track and timing of individual cyclones. A detailed study of the model storms indicated that the thermal structure was captured with some realism while the intensity and the scale of the cyclones were misrepresented. This was partly explained by the coarse model resolution in the early 1980s, but also by the insufficient initialization procedures and the limitations in the physical parametrization (Bengtsson et al., 1982).

Since then, several improvements in the physical parametrization of the model, together with the introduction of a higher resolution both in the horizontal and vertical (T106 L19 at present), have led to a much improved representation of tropical cyclones and some successful forecasts during the last hurricane seasons in the North Atlantic. In particular the track and the timing of landfall of Hurricane Hugo in September 1989 was well predicted out to five days by the ECMWF model (Böttger and Bengtsson, 1990).

Fig. 9 gives an example of two 48-hour forecasts of MSL pressure from the UK Meteorological Office and ECMWF for a tropical cyclone in the western Pacific. Bearing in mind that both models are global with a resolution of 200 km or more in the free atmosphere the prediction of the vortex must be considered to be highly useful as guidance material to forecasters. ECMWF does not apply any manual intervention to the analysis, such as introduction of bogus data for better description of the position or the intensity of the tropical cyclone. In areas where tropical cyclones are captured by available observational data, the resulting forecasts usually feature the tropical storm and its further evolution in a realistic way. However, in data-sparse regions (the eastern Pacific, the southern oceans but occasionally also in the Atlantic) a poor analysis leads to an inadequate forecast. An example is shown in Fig. 10 where it is assumed that the superior representation of the vortex in the Meteorological Office forecast was achieved by means of bogussing.

Tropical cyclone data on position and intensity are regularly originated by some of the hurricane forecast centres and distributed via the GTS of WMO. ECMWF currently evaluates how such information can be utilised in its operational system for further improvement of tropical storm forecasting.

4. CONCLUSION

While there is evidence from objective and synoptic type model evaluation studies that there has been a significant improvement in the model's capability of predicting large scale tropical flow pattern and to some extent synoptic scale features, the analysis systems still suffer from inadequacies in the data availability and quality. Recent efforts within the World Weather Watch of the WMO have led to some improvements in the data coverage. Data producers must be made aware of the importance of the data for global weather analysis forecasting and climate research. The meteorological community requires the most complete and best quality data sets obtainable. Efforts must continue to exchange all the relevant observations for global forecasting in real-time and to improve their quality.

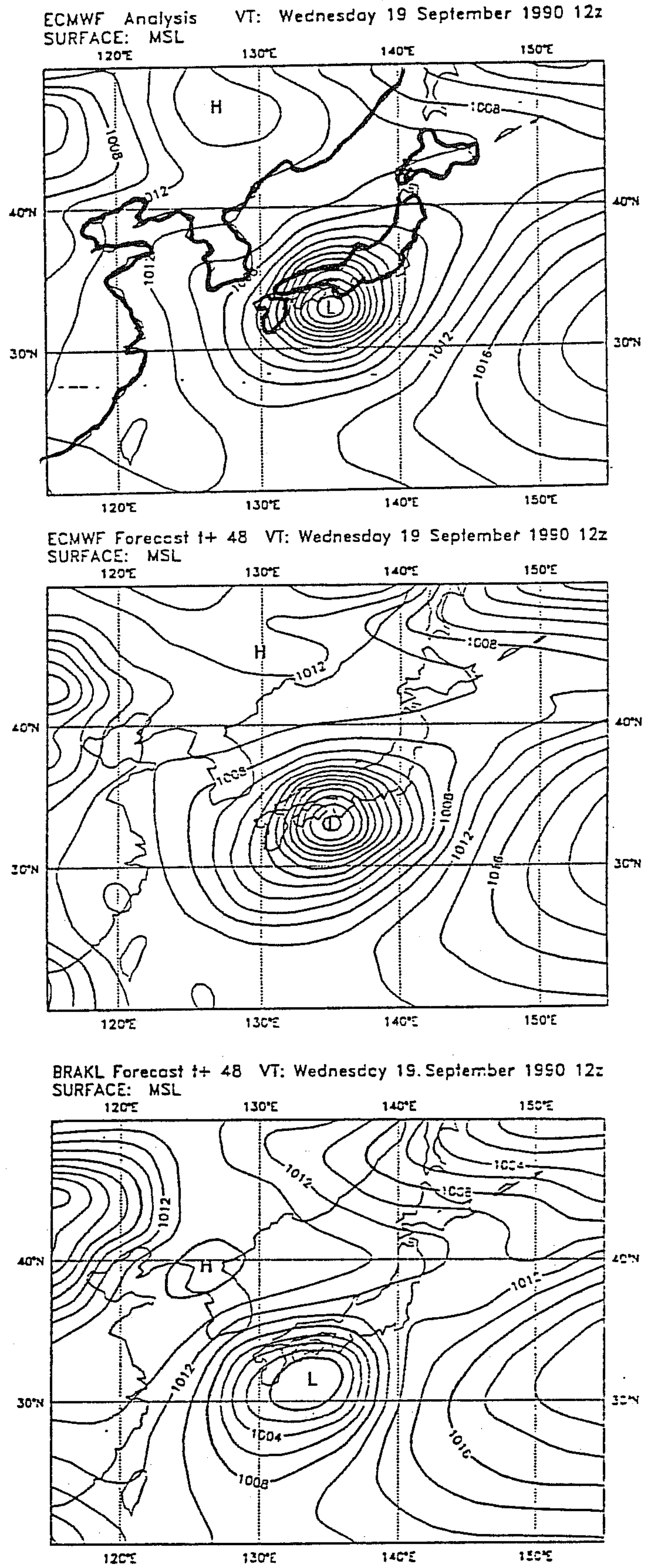
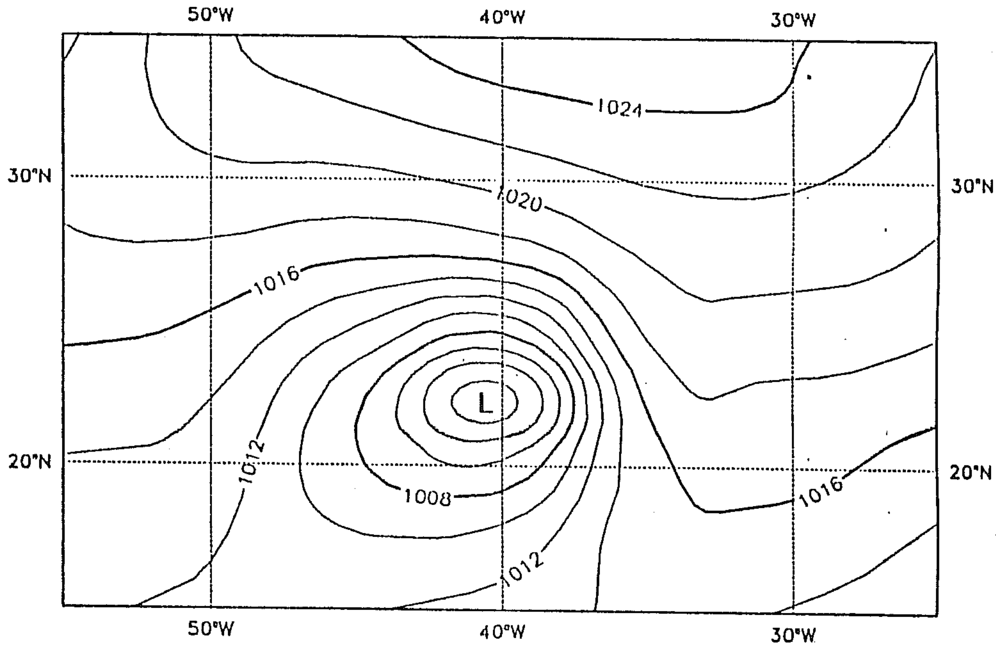


Fig. 9: 48 hr forecast of MSL pressure for a tropical cyclone in the western Pacific on 19 September 1990, 12 UTC, from ECMWF (centre) and the UK Meteorological Office (bottom) together with the verifying analysis (top)

BRAKL Forecast t+ 48 VT: Saturday 8 September 1990 12z
SURFACE: MSL



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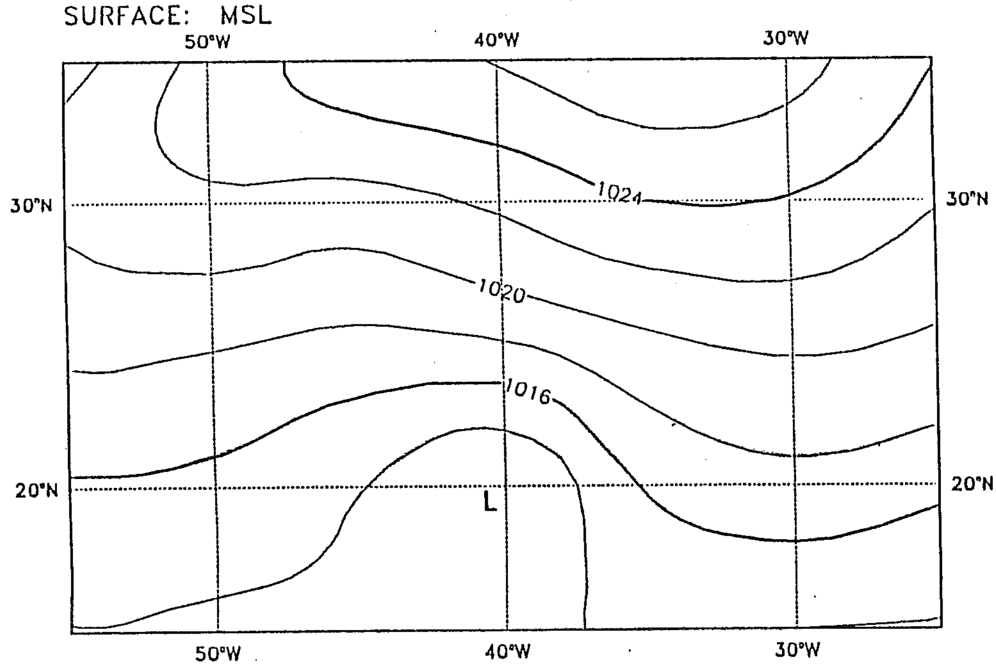

Fig. 10: 48 hr forecast of MSL pressure for a tropical cyclone in the central Atlantic on 8 September 1990, 12 UTC, from the UK Meteorological Office (top) and ECMWF (bottom)

<u>REFERENCES</u>

Baede, A.P.M., Kallberg, P., and Uppala, S., 1987: Impact of aircraft wind data on ECMWF analyses and forecast during the FGGE period 8-19 November 1979. O.J.R. Meteorol. Soc., 113, pp 871-898.

Bengtsson, L., Böttger, H., and Kanamitsu, M., 1982: Simulation of hurricane-type vortices in a general circulation model. Tellus, 34, pp 440-457.

Böttger, H., and Bengtsson, L., 1990: Simulation of Hurricane Hugo by the ECMWF operational forecast model. 70th Annual Meeting of the American Meteorological Society, 4-9 February 1990, Special Sessions on Hurricane Hugo.

Datta, R.K., Heckley, W.A., Illari, L., Miller, J.M., 1986: Prediction of monsoon flow over the Indian subcontinent by the ECMWF model, ECMWF Technical Memorandum No. 113.

Datta, R.K. and Hatwar, H.R., 1988: Prediction of monsoon rainfall over India with the ECMWF model, ECMWF Technical Memorandum No. 144.

Hollingsworth, A., Eriksson, A., Radford, A., and Rubli, A., 1991: A review of the TOGA IIa wind data and TOGA/ECMWF IIIa wind analyses, part 1 - upper level winds (in preparation).

Shaw, D.B., Lönnberg, P., Hollingsworth, A., and Undén, P., 1987: Data assimilation: The 1984/85 revision of the ECMWF mass and wind analysis. Q.J.R. Meteorol. Soc., 113, pp 533-566.