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# EVALUATION OF OPERATIONAL CYCLONE TRACK FORECASTS BY IMD LIMITED AREA NWP MODEL DURING 1998

1. A procedure for initialization (bogusing) of tropical cyclones with synthetic observations has been developed in India Meteorological Department (IMD) (Prasad, 1990; Prasad *et al.* 1992). Application of this procedure in predicting movement of cyclones by limited area numerical model was demonstrated by Prasad *et al.* (1997). In this work test runs have been carried out on several cases of tropical cyclones in the Indian seas and performance of the forecast model has been evaluated in terms of position errors and directional displacements of the predicted tracks *vis-à-vis* observed movements.

The cyclone bogusing procedure is invoked, whenever situation demands, with an operational limited area analysis forecast system (LAFS), which runs in the Delhi Office of IMD with real time GTS data. LAFS is based on a three dimensional multivariate optimum interpolation procedure for objective analysis (McPherson *et al.* 1979; DiMego *et al.* 1985), and a multilayer primitive equation limited area model (LAM) (Krishnamurti *et al.* 1990). The system operates on IMD's Cyber 2000U computer. The first guess fields for objective analysis and lateral boundary conditions for forecast model are prepared from global model forecasts produced by the National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi, which runs on a Cray supercomputer. Commencing from the post-monsoon cyclone season of 1998 the above procedure is operated in real-time to generate forecasts of cyclone movements in the Indian seas. Twelve hourly predicted positions are communicated, as numerical guidance information, to the field offices of India Meteorological Department concerned with cyclone warning work. There were three cyclonic storms during the 1998 post monsoon season, two in the Bay of Bengal and one in the Arabian Sea for which this guidance was provided. The procedure was also run in off-line mode (due to computer unserviceability problems) for another devastating cyclone, which formed during the month of June 1998 and hit Kandla in Gujarat. A computerized algorithm has been developed for calculating forecast errors in various forms. Kalsi (1998) has given a preliminary account of the performance of various NWP models (ECMWF, NCEP, NCMRWF and IMD LAM) in handling of the Kandla cyclone movement.

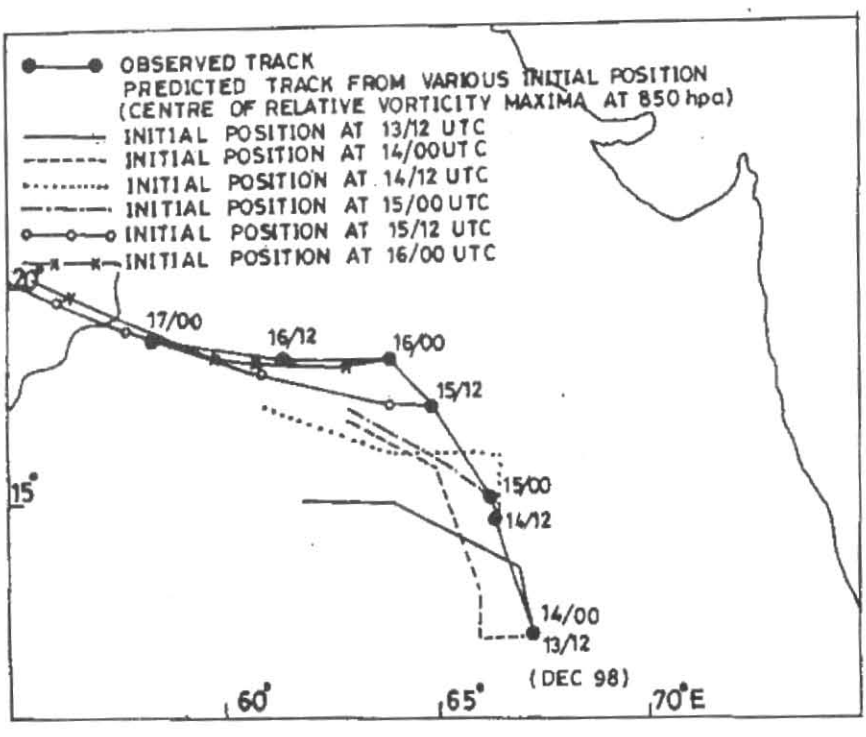


**Fig. 1.** Observed and predicted tracks of the cyclonic storm in Arabian Sea, 13-17 December 1998

**TABLE 1**

**24hr forecast verification (IMD LAM)**

| Valid date / Time (UTC) | Latitude error (km) | Longitude error (km) | Position error (km) | Vector error Length (km) | Vector error Angle (deg) |
|---|---|---|---|---|---|
| 15 Nov '98 / 0000 | -55.5 | 53.6 | 77.2 | -74.4 | 4.3 |
| 15 Nov '98 / 1200 | -222.2 | 159.9 | 273.8 | -272.7 | -5.3 |
| 16 Nov '98 / 0000 | -111.1 | 208.3 | 236.1 | -189.6 | 13.5 |
| Mean | -129.6 | 140.6 | 195.7 | -178.9 | 4.2 |
| RMS | | | | 196.5 | 8.8 |
| 20 Nov '98 / 0000 | -111.1 | 270.3 | 292.3 | -291.9 | 2.6 |
| 20 Nov '98 / 1200 | -222.2 | 107.4 | 246.8 | -239.4 | -8.2 |
| 21 Nov '98 / 0000 | -166.6 | 53.4 | 175.0 | -171.7 | -7.1 |
| 21 Nov '98 / 1200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 22 Nov '98 / 0000 | 0.0 | -104.5 | 104.5 | -16.3 | -17.6 |
| 22 Nov '98 / 1200 | 0.0 | -154.1 | 154.1 | -39.1 | -16.7 |
| 23 Nov '98 / 0000 | 55.5 | -102.5 | 116.6 | 2.4 | -19.5 |
| Mean | -63.5 | 10.0 | 155.6 | -108.0 | -9.5 |
| RMS | | | | 157.6 | 12.5 |
| 14 Dec '98 / 1200 | -55.5 | -53.9 | 77.4 | -22.8 | -14.9 |
| 15 Dec '98 / 0000 | -222.2 | -53.9 | 228.7 | -153.3 | -37.7 |
| 15 Dec '98 / 1200 | -111.1 | 106.6 | 154.0 | -145.7 | 12.2 |
| 16 Dec '98 / 0000 | 222.2 | 106.3 | 246.3 | -231.4 | -16.7 |
| 16 Dec '98 / 1200 | 0.0 | -52.9 | 52.9 | 51.1 | -2.0 |
| 17 Dec '98 / 0000 | -55.5 | 158.4 | 167.9 | -160.5 | -5.5 |
| Mean | -111.1 | 35.1 | 154.5 | -110.4 | -10.8 |
| RMS | | | | 145.6 | 18.7 |
| Mean (Over 3 cases) | -101.4 | 61.9 | 168.6 | -132.4 @ | -5.4 # |
| RMS | | | | 166.6 | 13.3 |

@ difference of vector length initial to forecast minus initial to observed; obtained by straight line joining of the initial and respective forecast positions

\# -ve sign indicates forecast track to the left of observed track

**TABLE 2**

**48 hr Forecast verification (IMD LAM)**

| Valid date / Time (UTC) | Latitude error (km) | Longitude error (km) | Position error (km) | Vector error | |
|---|---|---|---|---|---|
| | | | | Length (km) | Angle (deg) |
| 16 Nov '98 / 0000 | -444.4 | 105.1 | 456.7 | -417.6 | -13.1 |
| 16 Nov '98 / 1200 | -333.3 | -104.2 | 349.2 | -234.7 | -19.6 |
| Mean | -388.8 | 0.5 | 402.9 | -326.1 | -16.4 |
| RMS | | | | -338.7 | 16.7 |
| 21 Nov '98 / 0000 | 222.2 | 0.0 | 222.2 | 157.1 | 9.7 |
| 21 Nov '98 / 1200 | -111.1 | 159.1 | 194.0 | -175.8 | 7.0 |
| 22 Nov '98 / 0000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 22 Nov '98 / 1200 | 55.5 | 0.0 | 55.5 | 55.0 | -0.6 |
| 23 Nov '98 / 0000 | 55.5 | -307.6 | 312.6 | -20.4 | -27.2 |
| 23 Nov '98 / 1200 | 0.0 | 102.4 | 102.4 | 57.0 | 7.5 |
| 24 Nov '98 / 0000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mean | 31.7 | -6.6 | 126.7 | 10.4 | -0.5 |
| RMS | | | | 94.3 | 11.6 |
| 15 Dec '98 / 1200 | -222.2 | -320.7 | 390.1 | 64.5 | -34.9 |
| 16 Dec '98 / 0000 | -111.1 | -106.1 | 153.6 | -28.2 | -11.7 |
| 16 Dec '98 / 1200 | -111.1 | -53.0 | 123.1 | -9.5 | -10.8 |
| 17 Dec '98 / 1200 | 55.5 | -261.6 | 267.5 | 267.3 | -1.2 |
| Mean | -97.2 | -185.3 | 233.6 | 73.5 | -14.6 |
| RMS | | | | 138.3 | 19.2 |
| Mean over 3 cases | -151.4 | -63.8 | 254.4 | -80.7 @ | -10.5 # |
| RMS over 3 cases | | | | 190.4 | 15.8 |

@ difference of vector length initial to forecast minus initial to observed; obtained by straight line joining of the initial and respective forecast positions

# -ve sign indicates forecast track to the left of observed track

A detailed description of IMD's limited area analysis forecast system (LAFS) and the procedure for construction of synthetic observations and their use in the initialization of tropical cyclone vortices (Bogusing procedure) is given in an earlier paper (Prasad *et al.* 1997).

2. The performance of the forecast model was evaluated, qualitatively by plotting of the observed and predicted tracks side by side, and quantitatively by computing the forecast errors. The observed and predicted tracks in one typical case, that of 13-17 December 1998, is shown in Fig. 1. It may be seen that the model has been able to capture the westward tendency of movement of the system quite well. Similar agreement between the observed and predicted movements was seen in the other cases studied (not shown).

It is customary to evaluate the model performance in terms of the distance between the observed positions and the predicted positions at the terminal end of the forecast period, the so-called Direct Position Error (DPE). DPE is simply the resultant of the displacements in the latitudinal direction (Lat. Error) and longitudinal direction (Long. Error). While DPE gives an absolute measure of the error, it does not provide an idea of the biases in the speed and direction of the track. A clear picture of forecast error can be obtained by comparing the relative magnitudes of the observed and predicted displacements and relative angular deviations between the two tracks. With this end in view the length of the vectors from day 0 (initial) to day 1 (observed) and day 2 (observed) and day 0 to day 1 (predicted) and day 2 (predicted) were computed. The day 1 and day 2 positions were joined with the day 0 positions straight. The differences in magnitudes of the observed vector and predicted vector is designated as the vector error. The angular deviations between the observed and predicted vectors were also computed. Table 1 and Table 2 show the figures for various types of errors for 24 hr and 48 hr forecasts respectively. A summary of the statistics presented in the above Tables is given below for a ready comprehension-

| | | |
|---|---|---|
| Mean position error | : (24hr) | 169 km |
| | (48hr) | 254 km |
| Mean vector[@] error | : (24hr) | -132 km |
| | (48hr) | -81 km |
| RMS vector[@] error | : (24hr) | 167 km |
| | (48hr) | 190 km |
| Mean angular deviation[#] | : (24hr) | -5° |
| between observed and forecast vectors | (48hr) | -10° |
| RMS angular deviation | : (24hr) | 13° |
| between observed and forecast vectors | (48hr) | 16° |

The 'vector error' is computed as the difference of vector length initial to forecast minus initial to observed; obtained by straight line joining of the initial and the respective forecast positions. The angular deviation is computed as the angle between the observed and predicted vectors; -ve sign indicates forecast track to the left of observed track.

The mean position errors of 169 km for 24hr and 254 km for 48 hr forecasts in respect of the three cases in this study are comparable to the other state-of-the-art models running elsewhere in the advanced global NWP centres. As an illustration, the forecast errors of IMD limited area model have been compared with those of the UKMO global model, which were available in a readily published form (UKMO, 1998). The comparison statistics are presented in Table 3.

**TABLE 3**

**Comparison statistic of forecast errors in cyclone track prediction during 1998**

| Periods of cyclonic Storms | Direct position error (DPE) (km) 24 hrs | | 48 hrs | |
|---|---|---|---|---|
| | IMD | UKMO | IMD | UKMO |
| 05 – 10 June 1998 (Arabian Sea) | 185 | 129 | 180 | 191 |
| 13 – 16 November 1998 (Bay of Bengal) | 196 | 293 | 402 | N/A |
| 19 – 23 November 1998 (Bay of Bengal) | 156 | 178 | 127 | 331 |
| 13 – 17 December 1998 (Arabian Sea) | 154 | 183 | 234 | 395 |
| # All storms in 1998 in the north Indian Ocean | 173 | 185 | 236 | 302 |

The mean vector errors being negative for both 24hr and 48hr forecasts show some slow bias in the model predicted tracks. It is interesting to see that the negative bias in respect of the 48hr forecasts ( -81 km) is much less than the bias for 24hr forecast ( -132 km). The angular deviation between the observed and predicted tracks (mean and RMS both) is small, implying thereby that as far as the direction of movement is concerned, the model predicts it quite well.

3. The study has further established the skill of operational limited area model used in India Meteorological Department in forecasting the movement of cyclonic storms in the Indian seas, with a cyclonic vortex inserted in the initial fields with bogusing methodology. Though the model shows a somewhat slow bias in the speed of movement, it does provide a very useful guidance about the direction of movement with a 48 hr lead-time. This is amply borne out by the successful prediction of two contrasting cases, a northward moving and a westward moving system. The forecast errors of limited area model are comparable to the similar errors produced by some leading centres of the world, *e.g.*, UKMO. The guidance provided by the model forecasts can serve to enhance the degree of confidence in synoptic forecasting of tropical cyclone movement in the Indian seas.

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**References**

DiMego, G.J., Patricia, A., Phoebus and James, E., McDonell, 1'985, "Data processing, quality control and selection for optimum interpolation and analysis at the National Meteorological Centre", Proc. of workshop on the use and quality control of met. observations, 6-9 November 1'984, ECMWF, 325-368.

Holland, G.J., 1'980, "An analytical model of wind and pressure profiles in hurricanes", *Mon. Wea. Rev.*, **108**, 1212-1218.

Kalsi, S.R., 1998, "Some aspects of Gujarat cyclone of June 1998", Paper presented at the Indian Met. Soc. Symposium TROPMET-99, 16-19 February, 1999, Regional Met. Centre, Chennai.

Krishnamurti, T.N., Kumar Arun, Yap, K.S., Dastoor, Ashu P., Davidson, Noel and Sheng, J., 1990, "Performance of a high resolution meso-scale tropical prediction model", Advances in Geophysics, 32, Academic Press, INC., 133-286.

McBride, J.L., 1'986, "Observational analysis of tropical cyclone formation", *J. Atmos. Sc.*, **38**, 1117-1666.

McPherson, R.D., Bergman, K.H., Kistler, R.E., Rasch, G.E. and Gordon, D.S., 1979, "The NMC operational global data assimilation system", *Mon. Weath. Rev.*, **107**, 1445-1461.

Mesinger, F. and Arakawa, A., 1976, "Numerical methods used in atmospheric models", GARP Publ. Sr. No. 14, World Meteorological Organisation, Geneva.

Prasad, K., 1990, "Synthetic observations for representation of tropical cyclones in NWP data assimilation systems", Proceedings of the International symposium on assimilation of observations in Meteorology and Oceanography, Clermont-Ferrand, France, July 9-13, 1990, 581-587.

Prasad, K., Singh, B.V. and Hatwar, H.R., 1992, "Objective analysis and track prediction of tropical cyclones with synthetic data", Physical processes in atmospheric models, edited by D.R. Sikka and S.S. Singh, Wiley Eastern Ltd., 349-363.

Prasad, K., Rama Rao, Y.V. and Sen, Sanjib, 1997, "Tropical cyclone track prediction by a high resolution limited area model using synthetic observations", *Mausam*, **48**, 3, 351-366.

U.K.M.O., 1998, "Monthly summary of tropical cyclone activity and forecasts", June 1998, November 1998, December 1998, U.K. Met. Office, Bracknell.

K.PRASAD
S. R. KALSI
Y.V. RAMA RAO
S. K. ROY BHOWMIK
D. JOARDAR

*Meteorological Office*
*New Delhi-110 003, India*
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