EVALUATION OF THE QUASI-LAGRANGIAN MODEL FOR CYCLONE TRACK PREDICTION IN BAY OF BENGAL AND ARABIAN SEA

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OUTLINE

- **Quasi-Lagrangian Model**
- **Experiments for cyclones in the Bay of Bengal and Arabian Sea for the period 2000-2004 using NCMRWF initial and boundary conditions**
- **Experiments for past historical cases of tropical cyclones which hit the east coast of India and Bangladesh coast using ECMWF Re-analysis (ERA-40), NCEP GFS initial and boundary conditions**
- **Performance Evaluation**
- **Concluding remarks**

- Quasi-Lagrangian model (QLM) for cyclone track prediction was implemented in year 2000 in India Meteorological Department (RSMC-Tropical Cyclones, New Delhi) for providing numerical guidance in its cyclone forecasting operations.
- It uses the methodology of a synthetic vortex superimposed on gridded fields to correct the location and intensity of the vortex in the initial fields.
- It has a horizontal resolution of 40 km and 16 sigma levels in the vertical with a domain of about 4400x4400 km2 area that is centered on the initial position of the cyclone.
- The special feature of the QLM is an idealized vortex, which is generated from the current storm parameters; and a Dipole, which is generated based on the estimated storm speed and direction.
- The synthetic vortex thus obtained is incorporated in the background initial analysis by a merging process. The basic data sets used are obtained from the global T-80 model sigma fields operationally run at National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi.

QUASI-LAGRANGIAN MODEL

DATA INPUT : SYNOP, PILOT, SATEM, SATOB, AIREP, AMDAR, DRIBU
FIRST GUESS :
OBJECTIVE ANALYSIS: 3-D MULTIVARIATE OPTIMUM INTERPOLATION

VARIABLES : GEOPOTENTIAL (Z), TEMPERATURE (T), ZONAL (U) & MERIDIONAL (V) COMPONENTS OF WIND, SPECIFIC HUMIDITY (Q)

FORECAST MODEL:
BOUNDARY CONDITIONS: GLOBAL MODEL T80 FORECASTS, NCMRWF, NEW DELHI

RESOLUTION : 40 KM, 16 SIGMA LEVELS

INTEGRATION : VARIABLE -CENTRE ON THE INITIAL POSITION OF CYCLONE
DOMAIN : 40° X 40° (APPROX)
INPUT FIELDS : Z,T,U,V,RH
OUTPUT FIELDS : 12, 24H,48H & 72H FORECAST TRACK,SURFACE PRESSURE Z,T,U,V,RH AT 10 PRESSURE LEVELS; RAINFALL AND FIELDS OF DERIVED PARAMETERS SUCH AS VORTICITY, DIVERGENCE, VERTICAL VELOCITY

QLM Model – Error Statistics

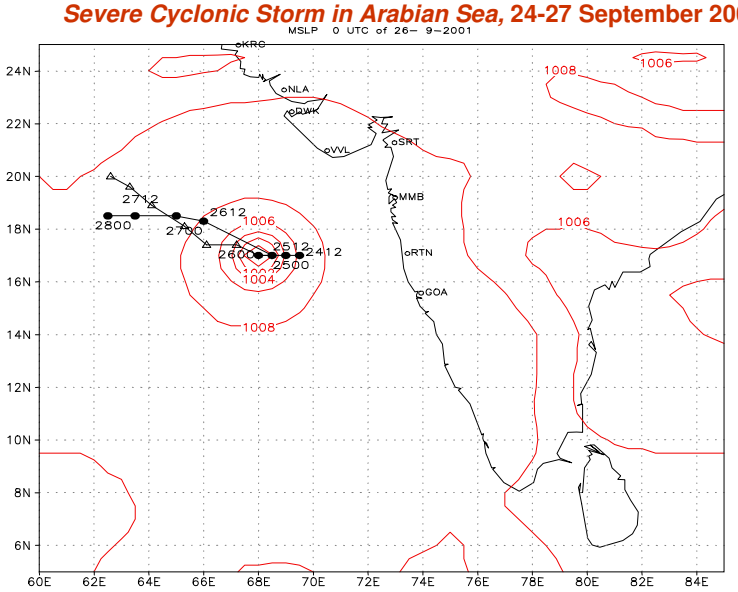
Year	24-hour forecast	36/48-hour forecast	72-hour forecast
1998	143(2)**	224	--
1999	119(3)	248	--
2000	100(3)	173	--
2001	106(3)	183	--
2002	150(2)	115	425(2)
2003	187(3)	251	280(2)
2004	176(4)	223(4)	240(2)
2005	174(4)	306(4)	345
Mean Error	144	215	315

** No. of cases

Experiments for cyclones in the Bay of Bengal and Arabian Sea for the period 2000-2004 using NCMRWF initial and boundary conditions

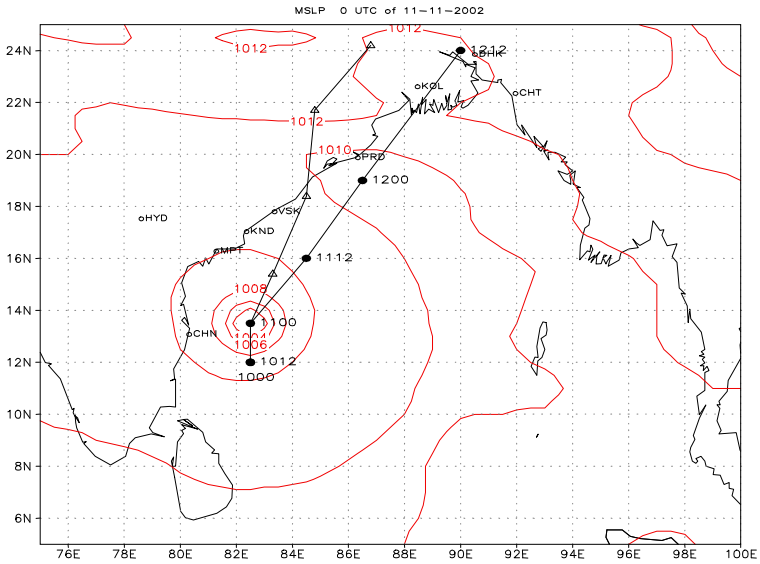
- **The original version of the model adapted in IMD was providing the cyclone track forecasts upto 36 hours. Subsequently the model in collaboration with SAARC Meteorological Research Centre (SMRC), Dhaka was upgraded to provide track forecasts upto 72 hours and made operational in 2004.**
- **The modified version was further tested for some historical cyclones in the Bay of Bengal and Arabian Sea for the period 2000-2004 using NCMRWF initial and boundary conditions.**

Severe Cyclonic Storm in Arabian Sea, 24-27 September 2001



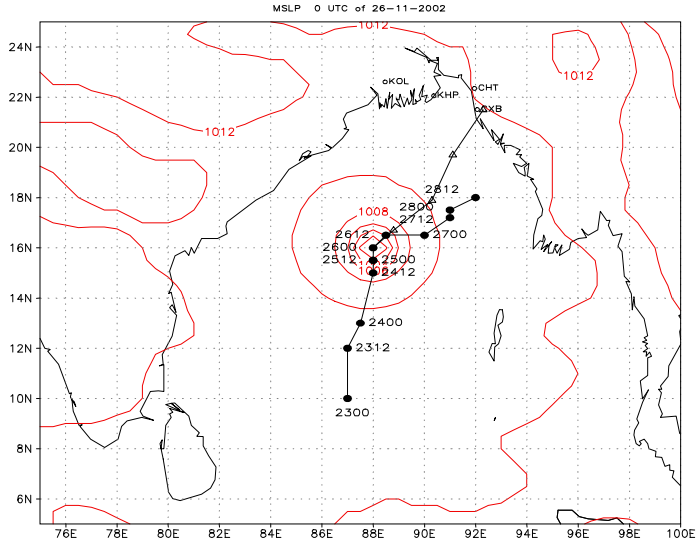
Mean sea level pressure (hPa) analysis valid 00 UTC of 26 September 2001 and track forecast based on **26 September/00 UTC initial conditions** with idealized vortex (circle: observed; triangle: predicted)

Cyclonic storm in Bay of Bengal, 10-12 November 2002



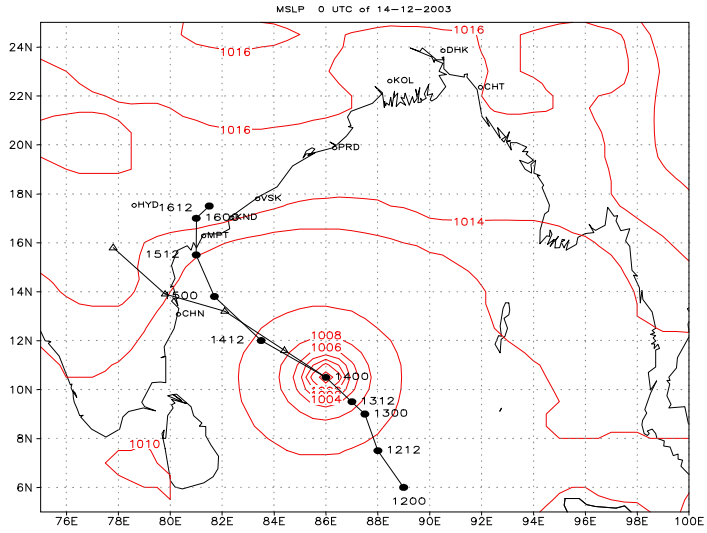
Mean sea level pressure (hPa) analysis valid 00 UTC of 11 November 2002 and track forecast based on **11 November/00 UTC initial conditions with idealized vortex** (circle: observed; triangle: predicted)

Cyclonic storm in Bay of Bengal, 23-28 November 2002



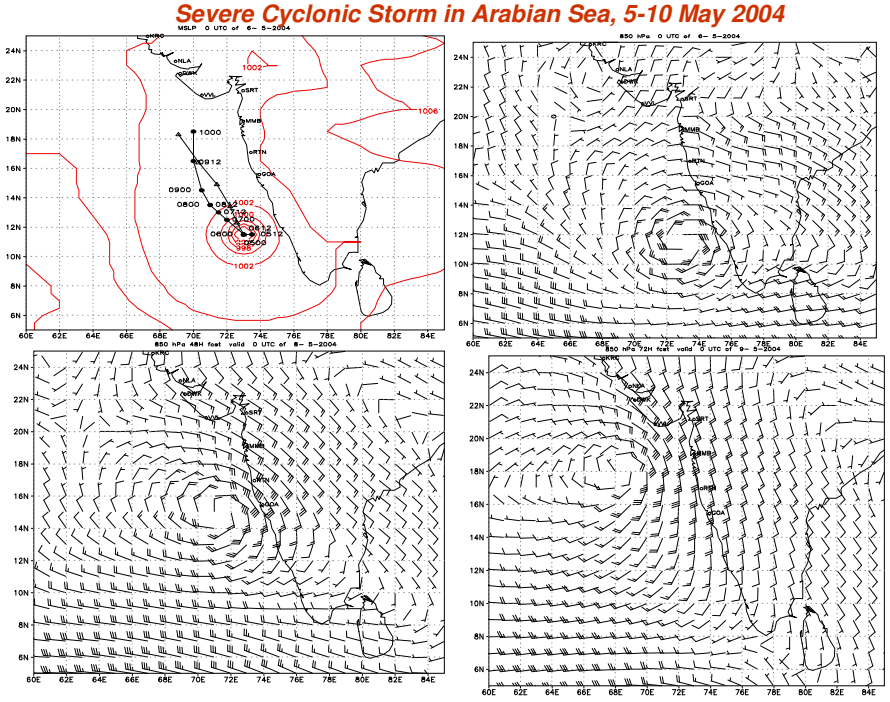
Mean sea level pressure (hPa) analysis valid 00 UTC of 26 November 2002 and track forecast based on 26 November/00 UTC initial conditions with idealized vortex (circle: observed; triangle: predicted)

Severe cyclonic storm in Bay of Bengal, 11-16 December 2003

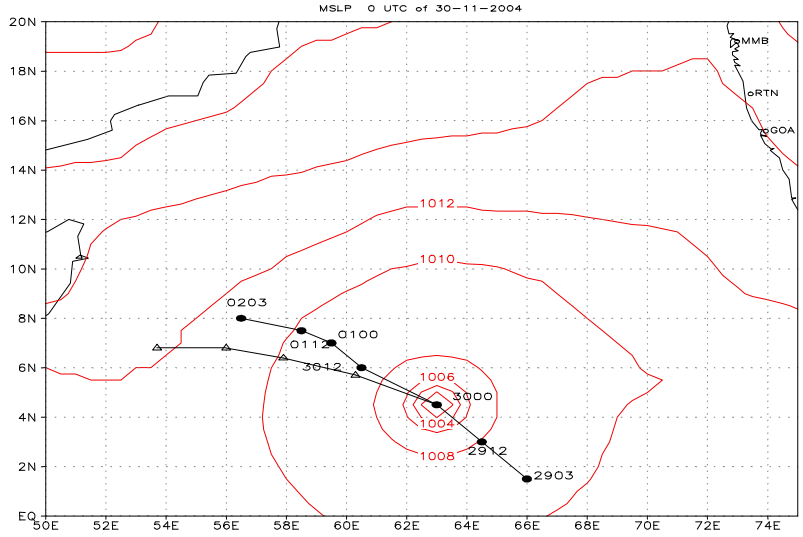


Mean sea level pressure (hPa) analysis valid 00 UTC of 14 December 2003 and track forecast based on 14 December/00 UTC initial conditions with idealized vortex (circle: observed; triangle: predicted)

Severe Cyclonic Storm in Arabian Sea, 5-10 May 2004



Severe cyclonic storm 'Agni' in the Arabian Sea, 29 Nov.-03 Dec. 2004



Mean sea level pressure (hPa) analysis valid 00 UTC of 30 November 2004 and track forecast based on 30 November/00 UTC initial conditions with idealized vortex (circle: observed; triangle: predicted)

Forecast Verification

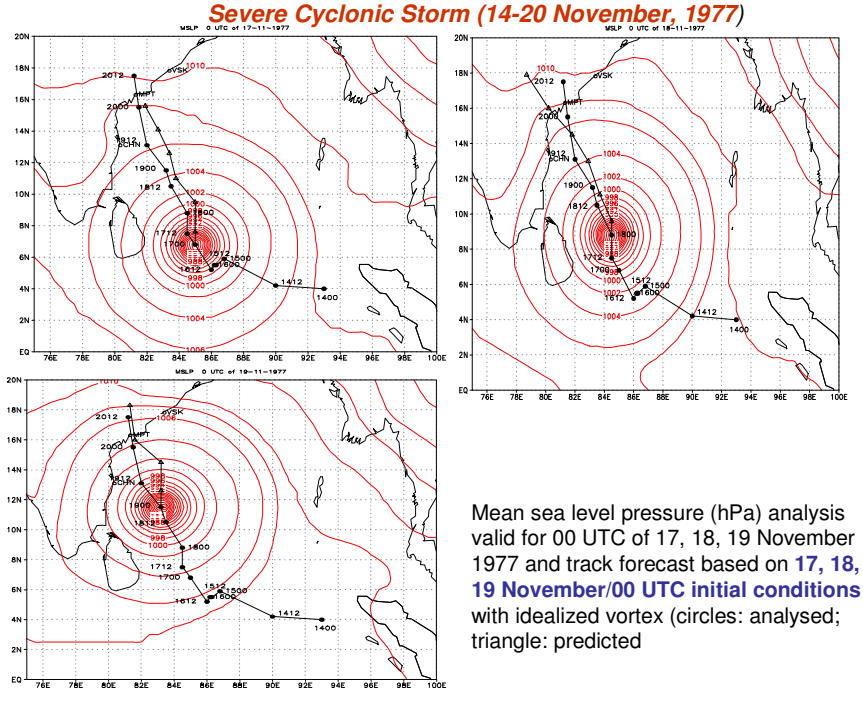
Forecast hour	Direct Position Errors (KM) 12	24	36	48	60	72
Initial Date						
0 25 09 01	49.3	123.2	38.7	133.0	236.3	
0 26 09 01	161.6	168.7	195.2			
0 15 10 01	109.2	168.4	266.5			
0 10 11 02	135.1	128.6	337.5	610.2	952.0	
0 11 11 02	174.3	231.0	511.2			
0 24 11 02	103.9	106.3	216.8	295.1	438.1	576.4
0 25 11 02	172.0	343.9	493.5	722.2	813.7	676.4
0 26 11 02	10.7	147.9	289.1	507.4		
0 13 12 03	155.1	404.6	524.1	737.5		
0 14 12 03	122.2	85.8	224.1	370.7		
0 06 05 04	0.0	117.1	64.3	168.5		
0 07 05 04	77.6	102.9	160.5	241.8	197.0	172.6
0 08 05 04	125.3	132.7	182.7	334.8		
0 09 05 04	133.9	233.3				
0 29 11 04	80.1	144.7	165.1	209.3	192.7	307.6
0 30 11 04	47.0	164.3	279.3	373.4	447.6	
Mean error	**103.6**	**175.2**	**263.2**	**392.0**	**468.2**	**433.2**
Mean Errors of QLM model (1997-2000)		**122**		**256**		**415**
Mean Errors of UKMO model (2000-2004)*		**175**		**301**		**424**

Experiments for past historical cases using ECMWF Re-analysis (ERA-40), NCEP GDAS & GFS initial and boundary conditions

- Recently, the QLM code have been modified to receive inputs from a global analysis and forecast system in the grid point form and thus to delink the model from the spectral form of inputs, with which the original version of model was tied up.
- The modified model was used to test its success using some past historical cases of tropical cyclones which hit the east coast of India and Bangladesh coast.
- In these experiments the basic data sets drawn from the ECMWF Re-analysis (ERA-40), NCEP GFS.
- The use of GFS data is of particular significance in view of its potential in the real time forecasting operations. The case of 'MALA' in April 2006, the most recent cyclone in Bay of Bengal was experimented upon with real-time GFS data.

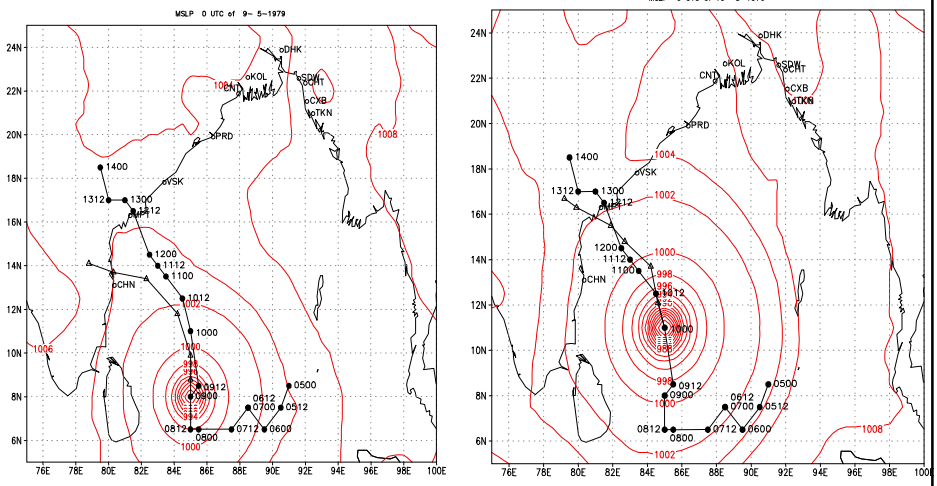
- Mathur (1991) introduced the concept of superimposing dipole winds on the idealized vortex in westward moving storms to overcome the problem of poleward drift in the model forecast tracks.
- In track prediction experiments it was observed that while the westward moving storms were forecasted well, the superimposition of the dipole winds in the case of northward moving storms introduced a general westward bias in the forecast tracks.
- In the present study, experiments have been conducted with idealized vortex without dipole winds on northward moving and recurving storms as they constitute a difficult forecast problem.

Severe Cyclonic Storm (14-20 November, 1977)



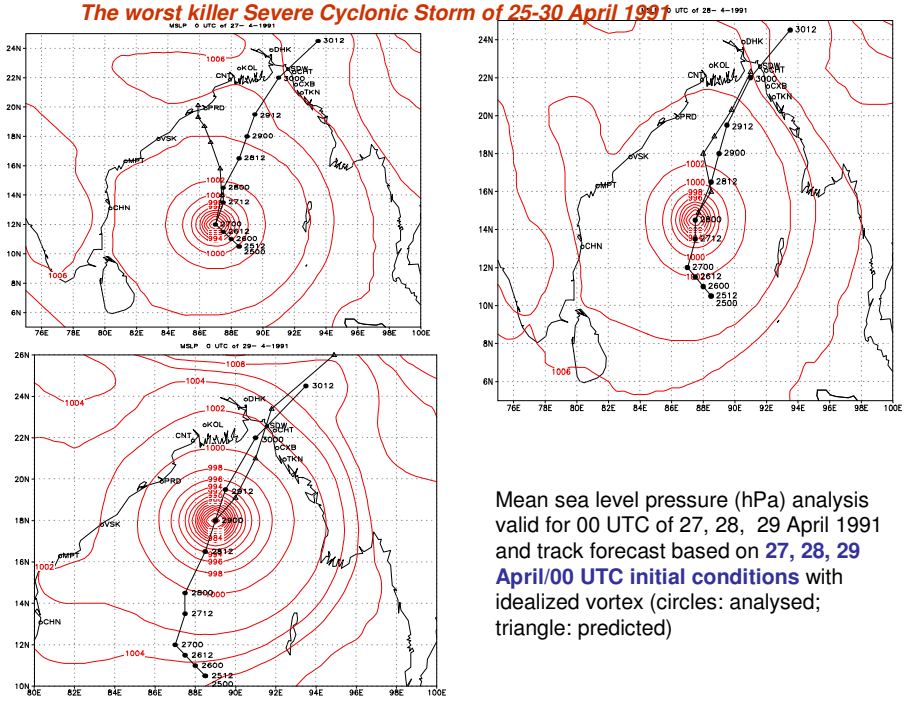
Mean sea level pressure (hPa) analysis valid for 00 UTC of 17, 18, 19 November 1977 and track forecast based on **17, 18, 19 November/00 UTC initial conditions** with idealized vortex (circles: analysed; triangle: predicted

Severe Cyclonic Storm over Bay of Bengal (05-13 May 1979) during the FGGE year



Mean sea level pressure (hPa) analysis valid for 00 UTC of 9, 10 May 1979 and track forecast based on **09 and 10 May/00 UTC initial conditions** with idealized vortex (circles: analysed; triangle: predicted)

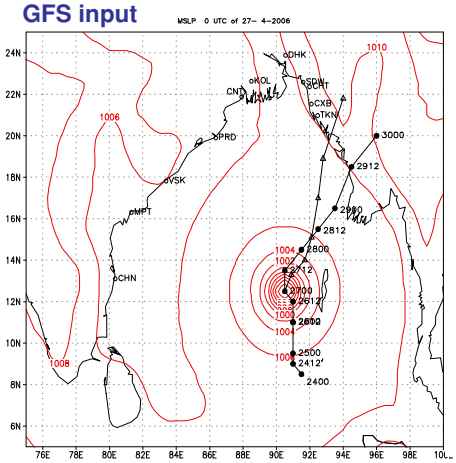
The worst killer Severe Cyclonic Storm of 25-30 April 1991



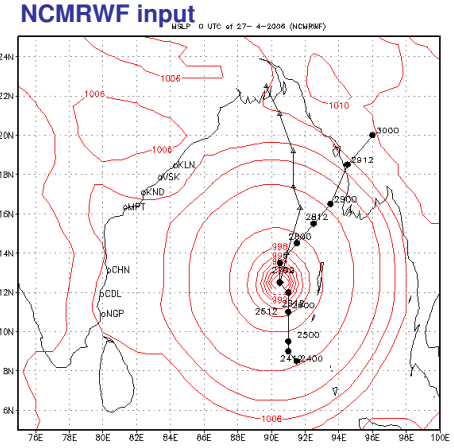
Mean sea level pressure (hPa) analysis valid for 00 UTC of 27, 28, 29 April 1991 and track forecast based on **27, 28, 29 April/00 UTC initial conditions** with idealized vortex (circles: analysed; triangle: predicted)

Severe Cyclonic Storm 'MALA' over Bay of Bengal (25-29 April 2006)

GFS input



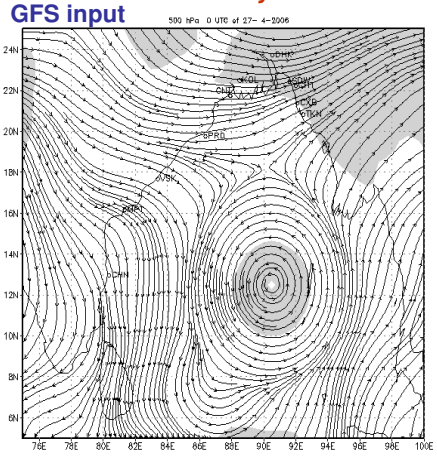
NCMRWF input



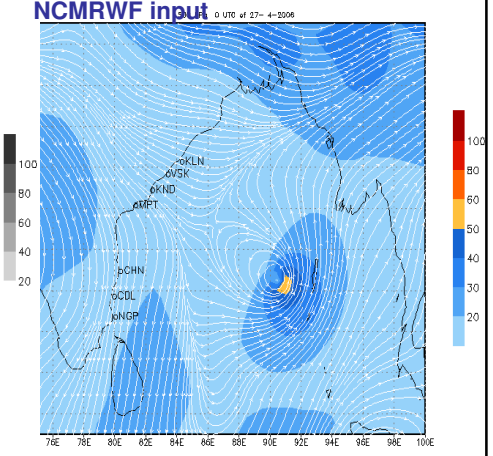
Mean sea level pressure (hPa) analysis valid for 00 UTC of 27 April 2006 and track forecast based on **27 April/00 UTC initial conditions** with idealized vortex (circles: analysed; triangle: predicted)

Severe Cyclonic Storm 'MALA' (25-29 April 2006)

GFS input

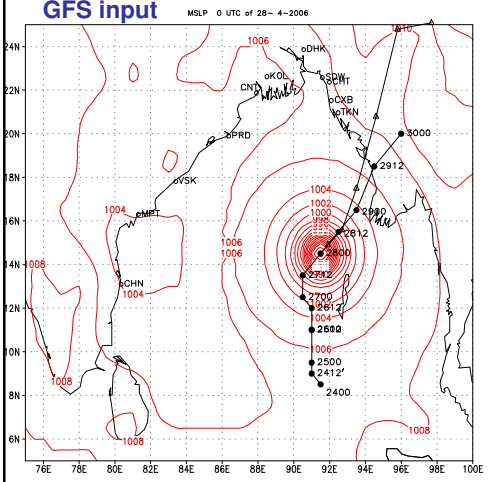


NCMRWF input

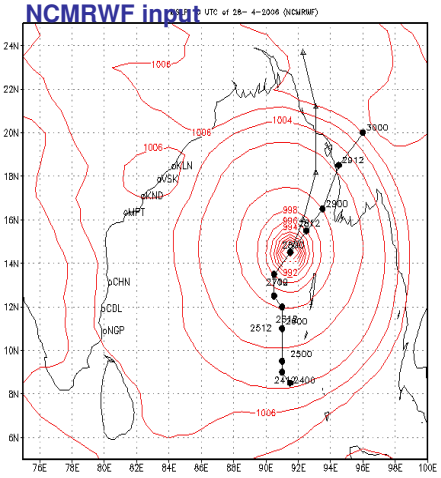


500 hPa wind analysis valid for 00 UTC of 27 April 2006 and track forecast based on **27 April/00 UTC initial conditions** with idealized vortex (circles: analysed; triangle: predicted)

GFS input



NCMRWF input



Mean sea level pressure (hPa) analysis valid for 00 UTC of 28 April 2006 and track forecast based on **28 April/00 UTC initial conditions** with idealized vortex (circles: analysed; triangle: predicted)

DIRECT POSITION ERRORS (KM)

Forecast hour / Initial date	12	24	36	48	60	72
16 11 77	124	162	289	362	303	400
17 11 77	56	95	64	124	134	44
18 11 77	148	70	98	116	198	
19 11 77	141	214	172			
8 5 79	100	49	168	215	383	455
9 5 79	64	122	84	130	293	401
10 5 79	46	79	95	128	172	194
11 5 79	35	60	32	163	266	313
27 4 91	57	146	227	295	378	570
28 4 91	197	228	230	420	602	
29 4 91	69	111	212			
7 11 95	242	253	390	415	556	462
8 11 95	253	360	380	245		
22 11 95	184	158	143	68	188	315
23 11 95	164	267	320	422	629	
24 11 95	190	246	424			
25 11 95	419					
27 4 6	49	60	62	120	184	288
28 4 6	93	132	153	171		
29 4 6	158	97				
Mean error	**139**	**153**	**197**	**226**	**330**	**344**

'Direct Position Error' (DPE) is the geographical distance between the predicted location of the storm and the verifying position at valid hour.

FORECAST ERRORS

Col. 1:Vector Difference (Km) Col. 2:Angular Deviation (Deg.)

Forecast hour	12		24		36		48		60		72	
Initial date	1	2	1	2	1	2	1	2	1	2	1	2
16 11 77	59	-60	117	26	250	21	353	8	262	12	375	9
17 11 77	-6	35	71	14	42	6	110	6	76	8	-5	2
18 11 77	-129	30	-62	6	-52	9	-114	-1	-104	-10		
19 11 77	-98	36	-148	22	-172	-1						
8 5 79	-11	90	-35	0	48	-19	-6	-22	-9	-31	4	-31
9 5 79	11	-45	-122	0	-72	-5	36	-11	114	-21	186	-24
10 5 79	-46	-2	-10	14	93	3	128	1	88	-11	96	-12
11 5 79	21	18	33	17	18	-4	146	-8	259	5	278	10
27 4 91	51	-7	140	-7	98	-21	48	-24	-56	-26	-282	-28
28 4 91	-197	0	-222	10	-202	-13	-406	-9	-588	-9		
29 4 91	-13	23	-97	7	-193	-7						
7 11 95	-232	37	-250	8	-385	-6	-388	-10	-350	-20	-19	-15
8 11 95	-251	-8	-355	8	-377	-3	-242	-2				
22 11 95	-183	9	-153	7	-132	6	-60	-2	8	-10	2	-13
23 11 95	-162	10	-264	-5	-288	-12	-340	-14	-515	-15		
24 11 95	-179	16	-246	0	-415	-5						
25 11 95	-415	9										
27 4 6	-12	26	-36	12	-60	-2	-5	-13	-40	-14	79	-15
28 4 6	-93	0	-131	3	-152	-3	-3	-13				
29 4 6	-158	3	-66	-9								
Mean error	-102	11	-97	7	-108	-3	-53	-8	-66	-11	54	-12
RMSE	156	32	163	12	209	10	214	12	265	16	197	18

Performance Evaluation

The mean error works out (6 cases) to 153 km for 24 hour forecast, 226 km for 48h forecast and 344 km for 72h forecast. Two facts emerge from these statistics:

- The mean errors in all the forecast ranges are negative except in the 72 hour range, which indicates a slow bias in the predicted speed of movement; and
- The RMSE Angular Deviations are small, being within 20 degrees for all forecast ranges except in the 12 hour range.

Improvement in Global model forecast (initial and boundary conditions) will improve the model environment fields.

The present version of the model is only for track prediction. Intensity prediction is one of the major problems.

Concluding remarks

- The main objective of this work was to modify the QLM codes to receive inputs from a global analysis and forecast system in the grid point form readily available on Internet and to delink the model from the spectral form of inputs, with which the original version of model was tied up.
- Performance evaluation forecast error statistics in various forms indicated that while the forecast errors are reasonable, the direction of movement of the storms, largely northward and recurving northeastward in the cases under study, is well captured by the model.
- An indication about the most likely direction of movement and the most likely part of the coastline to be struck by the storm, 48 to 72 hours in advance, when the storm is located in the southern parts of Bay of Bengal and has the possibility of striking any part of the long coastline, may be considered a good numerical guidance for the forecasters.
- As future plan, we are expecting to test the model with 20 km horizontal resolution.
- As a part of INDO-USAID program, IMD planning to adapt H-WRF model for Tropical cyclone track and Intensity prediction.

THANKS