

# Performance of NCMRWF Model TC Track Forecasts During 2013

R. Ashrit, A. Ashish, K. Sharma, A. Dube, I. Rani, M. Dasgupta,  
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## 1 Introduction

There are two tropical cyclone (TC) seasons over the North Indian Ocean (NIO), (including the Bay of Bengal (BOB) and the Arabian Sea (AS)), i.e. during the pre-monsoon months (April–early June) and the post-monsoon months (October–December) (Mohanty et al. 2010). Further the Indian subcontinent happens to be one of the world's highly vulnerable areas since the coastal population density is very high leading to an extensive damage to life and property. Therefore, forecasting of TC track and landfall location is critical for early warnings and mitigation of disaster. Track forecast errors over the NIO though improved significantly in recent years (Mohapatra et al. 2013, 2015) are still high relative to those over the Atlantic and Pacific Oceans. With advancements in computational power, development of better NWP models (both global and regional), the forecasting capability of meteorologists have greatly increased. Several meteorological centers like NCEP, UKMet office, ECMWF, JMA, JTWC etc give a real time forecast of TC tracks from their global NWP models (deterministic as well as Ensemble Prediction Systems (EPS)) (Hamill et al. 2011; Froude et al. 2007; Buckingham et al. 2010; Heming et al. 1995; Heming and Radford 1998). TC track prediction from an ensemble forecasting system besides providing a track from each ensemble member also provides the strike probability (Weber 2005). For the TCs of NIO, Mohapatra et al. (2013, 2015) provided a detailed verification of the official forecast tracks and its improvements in the recent past. This study provides a detailed verification of the NCMRWF NWP model forecasts of 2013 TC cases. Some of the earlier studies (Ashrit et al. 2014; Chourasia et al. 2013 and Mohandas and Ashrit 2014) focused

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on the NCMRWF model TC forecasts and the impact of bogusing, assimilation and cumulus parameterisation etc. The present study is focused on the real time operational forecasts provided to India Meteorological Department (IMD). During May–December 2013, there were five TCs observed in the Bay of Bengal namely: Viyaru (May10–17), Phailin (October 4–14), Helen (November 19–23), Lehar (November 19–28) and Madi (December 6–13). This report summarises the performance of the real time prediction of these TC tracks by the NCMRWF Global Forecast Systems.

A brief description of the TC history is given in this section. It is followed by details on the modelling systems operational at NCMRWF and the TC tracking methodology in the Sect. 2. Verification results of the TC forecast tracks during 2013 are discussed in Sect. 3. The Summary of the results is discussed in Sect. 4.

### ***1.1 Brief Description of the Tropical Cyclones During 2013***

The first case is the cyclonic storm (CS) ‘Viyaru’ during 10–17 May 2013. It originated from an area of low pressure over the southern Bay of Bengal around 10 May 2013 which attained its peak intensity with winds of 85 km/h (50 mph) and a barometric pressure of 990 mb on 16 May 2013 (RSMC, New Delhi 2014). Shortly, thereafter Viyaru made landfall near Chittagong, Bangladesh. On May 17, it moved over the eastern Indian state of Nagaland. The second case is a very severe cyclonic storm (VSCS) ‘Phailin’ that lasted during 9–12 October 2013. On 4 October 2013, it started as a tropical depression within Gulf of Thailand and started tracking westwards into Bay of Bengal. On 9 October 2013, it was named ‘Phailin’ which intensified into VSCS on 10 October 2013 which tracked towards Odisha coast. It made landfall on 12 October 2013, near Gopalpur in Odisha coast at around 2130 IST (1700 UTC). It subsequently weakened over land as a result of frictional forces, before it was last noted on October 14, as it degenerated into a well-marked area of low pressure. Third case is of the severe cyclonic storm (SCS) ‘Helen’ that lasted during 19–23 November 2013. Emerging out of a well developed trough on 19 November 2013, ‘Helen’ intensified into a depression (D) and then into deep depression (DD) on same day and into CS and SCS on 21 November 2013 with peak intensity of 100 km/h (62 mph) with a central pressure of 990 mbar. It made landfall south of Machilipatnam, Andhra Pradesh and rapidly deteriorated into a deep depression. The VSCS ‘Lehar’ lasted during 23–28 November 2013. Emerging from a low pressure system in south China Sea that crossed to Andaman Sea on 22 November 2013, it intensified into D, DD and CS ‘Lehar’. On 25 November, it gradually consolidated further and was upgraded to a SCS by the IMD. The following day, Lehar further intensified into a VSCS. It featured peak winds of 140 km/h (87 mph) and a central pressure of 982 mbar. Thereafter, Lehar rapidly weakened into a depression and made landfall near Machilipatnam on 28 November 2013. The VSCS ‘Madi’ that lasted during 6–13 December 2013 is perhaps the most challenging case for any track forecasting system. The system first tracked northwards and then tracked in the southwesterly direction to cross the

Tamil Nadu coast. The D formed on the 6 December 2013 near Sri Lanka. It further strengthened into a CS, and was named Madi. Later on same day it further intensified into SCS. It gradually tracked northwards and was upgraded to VSCS on 8 December 2013. The system weakened on 9th and 10th while kept tracking northwards. It started tracking south-westwards on 10 December and kept weakening. On 12 December 2013, the system crossed Tamil Nadu coast twice with the intensity of a depression; first, near Nagapattinam at around 1200 UTC and the near Tondi at around 1700 UTC (Regional Specialised Meteorological Centre, New Delhi 2014).

## **2 Global Forecast Model Details and Tracking of TCs**

### ***2.1 NCMRWF Global Analysis and Forecast Systems***

The TC track forecasts are based on NGFS (T574L64) and the Unified Model (UM) of Met Office (NCUM) (Rajagopal et al. 2012) operational at NCMRWF. Additionally, the track and intensity forecasts based on the NCMRWF Global Ensemble Forecast System (GEFS; T190L28) are also provided to IMD on experimental basis. The NGFS (T574L64) and NGEFS (T190L28) forecasts are available out to 240 h while the NCUM forecasts are available up to 168 h. Table 1 lists some of the model configuration details for the two deterministic models (NGFS and NCUM). The ensemble system (NGEFS) is a 20 member ensemble system. The control for the ensemble system is obtained from the NGFS initial analysis. The NGEFS uses a set of 20 perturbed initial conditions to obtain 20 member forecasts. The perturbed initial conditions are obtained using the Ensemble Transform with Rescaling (ETR) method. The detailed description of the implementation of NGEFS at NCMRWF and its configuration is reported in (Ashrit et al. 2013).

### ***2.2 The Use of Observations Over the Ocean in the Model Initial Conditions***

Data coverage over the NIO has improved in recent years due to increased deployment of buoys and satellite (scatterometer) observations. These are assimilated in NCMRWF models NGFS and NCUM. Figure 1 shows the spatial coverage of surface and satellite observations over BOB for case of ‘Helen’ (18z20Nov 2013; *top panels*), ‘Lehar’ (06z24Nov 2013; *middle panels*) and ‘Madi’ (18z08Dec2013; *bottom panels*).

**Table 1** NCMRWF realtime global forecast model configurations

	NGFS	NCUM
Horizontal resolution	T574 (~23 km near equator) with a Gaussian grid of $1760 \times 880$ points	N512 (~25 km at mid-latitudes) with a EW-NS grid of $1024 \times 769$ points
Vertical levels	Hybrid sigma-pressure (64 levels)	70 vertical levels
Model time step	2 min	10 min
Forecast length	10 days	10 days
Data assimilation	Grid point Statistical Interpolation – GSI	4D var Data assimilation system
Dynamics	Spectral, hybrid sigma-p, reduced Gaussian grids	Non-hydrostatic dynamics with deep atmosphere. Height vertical coordinates with levels transitioning from terrain following to height. Global latitude–longitude grids
Time integration	Leapfrog/semi-implicit	Semi-implicit integration with 3D semi-Lagrangian advection

### 2.3 Tracking of TCs in the Global Model Analysis and Forecasts

The TC forecast tracks are derived based on vertical weighted average of the maximum or minimum of several parameters in the vicinity of a vortex in the input first guess (latitude and longitude) and forecasts (Marchok 2002). Briefly, for TCs, seven parameters are tracked, including the relative vorticity maximum, geopotential height minimum and wind speed minimum at both 850 and 700 hPa, as well as the minimum in sea-level pressure. The locations based on these parameters are averaged together to provide an average position fix at each forecast hour. In order to avoid tracking weak and transient disturbances (either real or artifacts of model noise), two constraints have been added to the tracking criteria in order for a found disturbance to be reported as being a tracked storm viz: (1) the storm must live for at least 24 h within a forecast, and (2) the storm must maintain a closed Mean Sea Level Pressure (MSLP) contour, using a 2 mb contour interval.

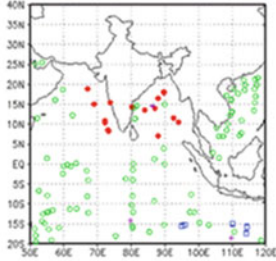
Based on the above described tracking algorithm, the TCs tracks are obtained from the two deterministic models; NGFS and NCUM, as well as from each of the ensemble members of NGEFS. Based on the location of tracked TC at any given time in each of the member forecasts, the tracker also provided ‘strike probability’ map. It is the probability of finding a TC within 100 km of the mean track. Thus, from the ensemble system, (i) mean track, (ii) member tracks and (iii) strike probability, the three products of importance to TC are obtained.

The real time forecast tracks based on NGFS and NCUM along with the mean track and strike probabilities based on NGEFS are provided to IMD.

Data Coverage: BUOY (20112013 1800UTC +/- 3 Hrs)

Total Number of Observations Received at NCMRWF: 518

country code in QTS as ● INDIA(31) ○ USA(436) + FRANCE(21) □ OTHERS(30)

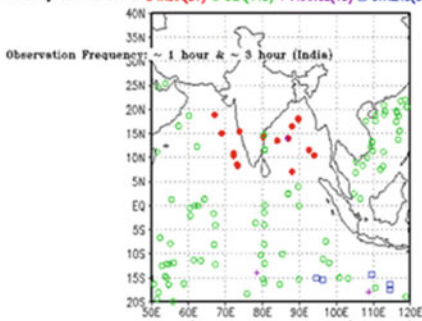


Observation Frequency: ~ 1 hour & ~ 3 hour (India)

Data Coverage: BUOY (24112013 0600UTC +/- 3 Hrs)

Total Number of Observations Received at NCMRWF: 525

country code in QTS as ● INDIA(31) ○ USA(443) + FRANCE(19) □ OTHERS(30)

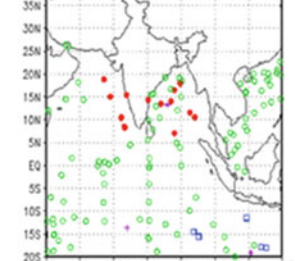


Observation Frequency: ~ 1 hour & ~ 3 hour (India)

Data Coverage: BUOY (08122013 1800UTC +/- 3 Hrs)

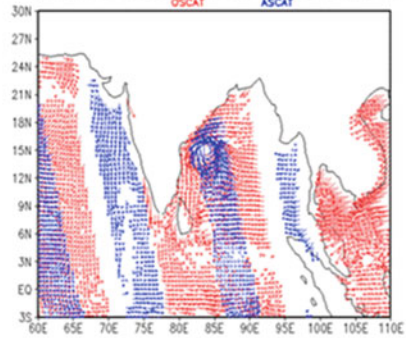
Total Number of Observations Received at NCMRWF: 619

country code in QTS as ● INDIA(31) ○ USA(538) + FRANCE(30) □ OTHERS(30)

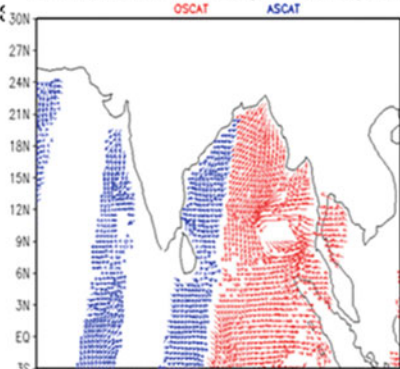


Observation Frequency: ~ 1 hour & ~ 3 hour (India)

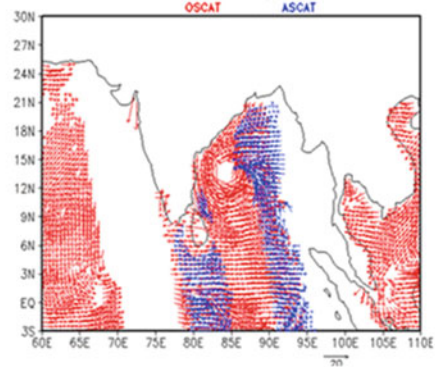
SCATTEROMETER SEA SURFACE WINDS (20112013 18 UTC):NCMRWF



SCATTEROMETER SEA SURFACE WINDS (24112013 06 UTC):NCMRWF



SCATTEROMETER SEA SURFACE WINDS (08122013 18 UTC):NCMRWF



**Fig. 1** The buoy data coverage (left panels) and the satellite scatterometer winds (right panels) over the Northern Indian Ocean (NIO) assimilated in NCMRWF model runs in respect of (i) TC Helen 20 Nov. 2013/18 UTC (ii) TC Lehar 24 Nov. 2013/06 UTC (iii) TC Madi 08 Dec. 2013/18 UTC

### 3 Verification of 2013 TC Track Forecasts

For verification of the TC forecast tracks, direct position error (DPE), along track error (ATE) and cross track error (CTE) are computed against the IMD reported best track data. Further, the forecast landfall position error and landfall time error are also computed.

#### 3.1 *'Viyaru' Forecast Tracks (11–16 May 2013)*

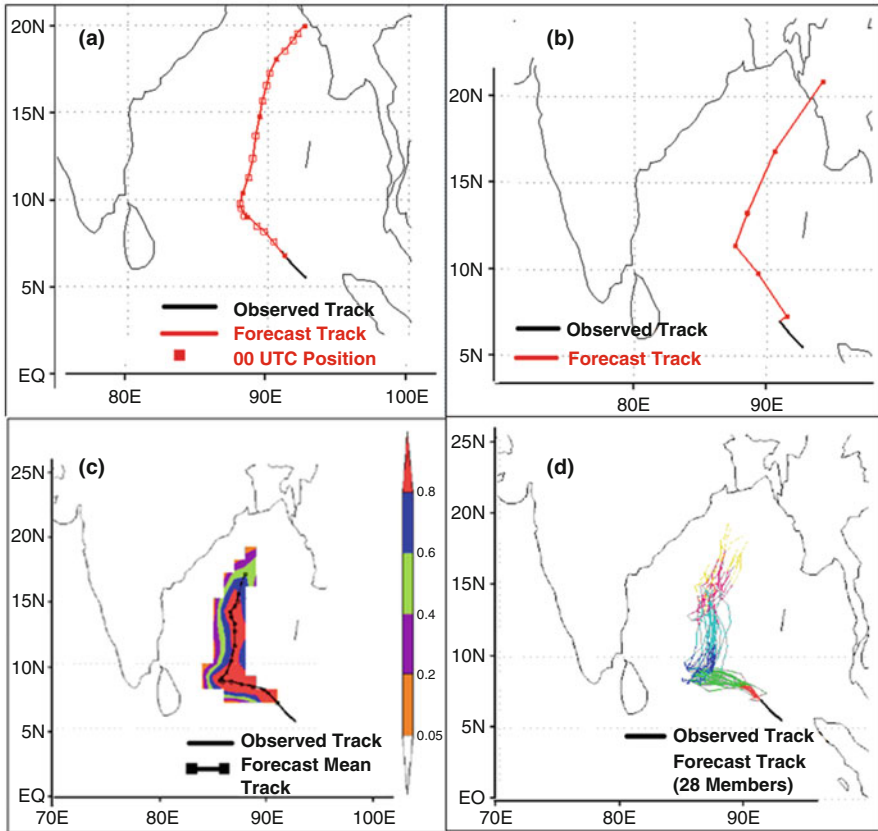
The forecast tracks based on the 00 UTC initial conditions from 11 to 16 May 2013 were generated and communicated to the IMD in near-real time. Figure 2 shows the forecast tracks based on the 00 UTC 11 May 2013 initial conditions. The forecast based on the two deterministic models (NGFS and NCUM) indicate landfall over Myanmar. NGEFS tracks consistently show movement towards Myanmar. The ensemble average track and strike probability are also shown. Strike probability is the probability of a given location (grid point) being within a specified distance (~101 km) of an ensemble member track point. Strike probability is calculated both individually for each forecast hour and for the total accumulated probability up to 120 h forecast.

##### 3.1.1 *'Viyaru' Forecast Track Errors (11–16 May 2013)*

Verification of forecast tracks is shown in Table 2. The average initial position error is lowest in the NGFS system at 52 km. The average forecast track error is lowest in NCUM in 24, 48 and 72 h forecasts. The average forecast track error in the NGEFS ensemble mean is consistently lower compared to NGFS at all lead times except at 120 h.

#### 3.2 *'Phailin' Forecast Tracks (9–12 October 2013)*

Figure 3 shows the forecast tracks based on the 00 UTC 9 October 2013 initial conditions. Forecast positions based on NGFS and NGEFS are shown at 6-h interval while the forecast positions based on NCUM is shown at 24-h interval. The forecasts indicate landfall over Andhra Pradesh and Odisha border. The forecasts closely match with the observed track although with a time delay as can be seen by the time indicated in the Fig. 3.



**Fig. 2** Observed and forecast tracks based on 00UTC 11th May 2013 initial conditions in (a) NGFS (T574L64) (b) NCUM and NGEFS (c) strike probability and (d) ensemble member tracks

**Table 2** Average forecast position errors (km) in the three modelling systems in respect of Viyaru (11–16 May 2013)

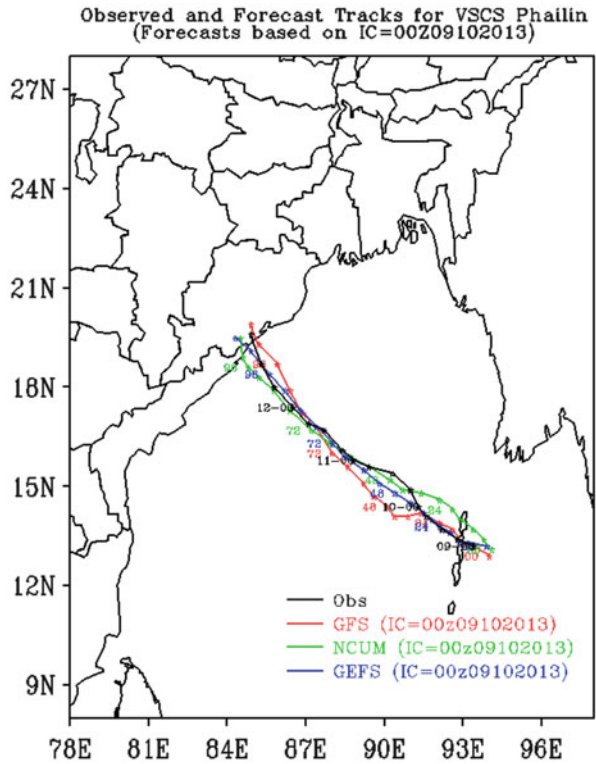
F/C hours	00	24	48	72	96	120
NGFS	52	205	383	542	584	324
NCUM	66	111	165	285	355	499
NGEFS	59	205	311	336	283	379

### 3.2.1 Forecast Track Errors (9–12 October 2013)

Forecast track errors are computed based on the TC positions from 00 UTC of 9–12 October 2013. The initial position errors in all three models are less than 50 km. The highest (lowest) initial position error of 45 km (26 km) is seen in NGFS (NGEFS) while the both NCUM model has initial error of 27 km. NCUM has the



**Fig. 3** Observed and forecast tracks of VSCS Phailin based on 9 October 2013



least position error at all lead times while NGEFS mean track consistently shows lower error than that of NGFS.

**3.2.2 Landfall Position and Time Error**

The IMD reported landfall is considered at 1500 UTC of 12 October 2013 at 19.1° N 85.0° E. Table 3 shows the landfall position and time errors based on all the available track forecasts. NCUM forecasts show least error in predicted landfall position and time with the exception of forecast based on 9 October 2013. NGEFS forecast can be considered next best. Similar to the forecast track errors discussed in the last section, NGEFS shows marginal improvement over the NGFS in predicting the landfall time and position.



**Table 3** Forecast landfall position error for VSCS Phailin in the ESSO-NCMRWF global models (IMD reported landfall at 15 UTC of 12 October at location 19.1° N, 85.0° E)

Initial conditions	NGFS		NGEFS		NCUM	
	Position error (km)	Time error (h)	Position error (km)	Time error (h)	Position error (km)	Time error (h)
IC = 09102013	31	-15	10	-6	47	-15
IC = 10102013	84	-15	70	-12	11	-3
IC = 11102013	42	-9	33	-9	39	-3
IC = 12102013	115	-15	78	-21	69	-3

### 3.3 'Helen' Forecast Tracks (20–22 November 2013)

The observed and forecast tracks from NGFS, NCUM and NGEFS (mean and control) are presented based on 21 November 2013 in Fig. 4. The forecast positions are shown at 6-h interval.

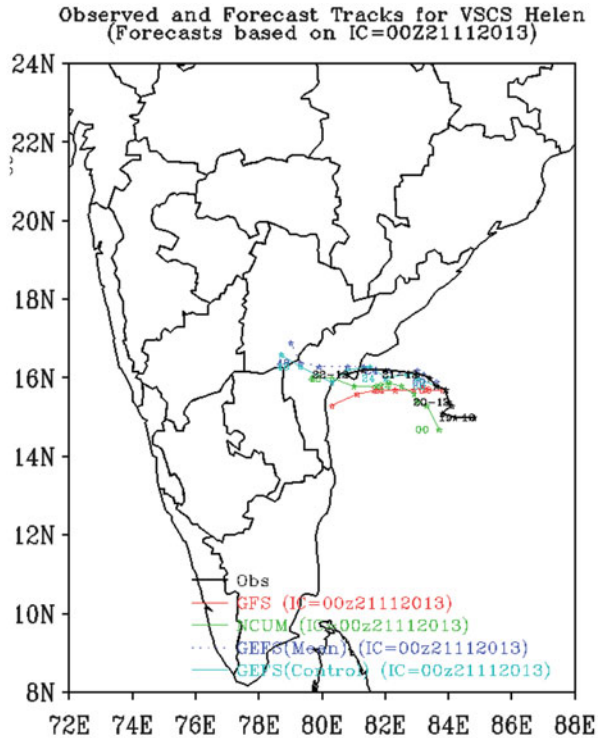
The forecast tracks of all three models are much to the south of observed track. In NCUM the initial position is also much to the south of observed location. Forecast tracks based on 20 and 22 November 2013 (not shown) suggest NGEFS mean track closely compares with observed track. The NCUM and GFS track forecast based on 21 and 22 are also considerably improved compared to the tracks based on 20 Nov 2013.

#### 3.3.1 Forecast Track Errors (20–22 November 2013)

Forecast track errors are computed based on 00 UTC TC positions from 20 to 22 November 2013 and average track errors are presented in Fig. 5a–c. The DPE, ATE and CTE are presented at 6-h interval up to 60 h. On one hand, positive (negative) values of ATE indicate that the movement of the TC in the forecasts is slower (faster) compared to the observations. On the other hand, positive (negative) values of CTE indicate that forecast track is right (left) of the observed track.

The initial position errors in NGFS and NGEFS models are less than 50 km. The highest (lowest) initial position error of 113 km (14 km) is seen in NCUM (NGEFS). NGEFS mean track shows least error at all lead times while NCUM shows highest average error at all lead times. NCUM and NGEFS mean tracks show relatively higher ATE up to 36 h varying from under 50 km to over 100 km. The prominently negative values in the CTE up to 54 h, shown in Fig. 5c indicate the forecast TCs tracks lie to the left of observed tracks. NGEFS mean track shows least CTE at all lead times.

**Fig. 4** Observed and forecast tracks of SCS Helen based on 21 November 2013/00 UTC



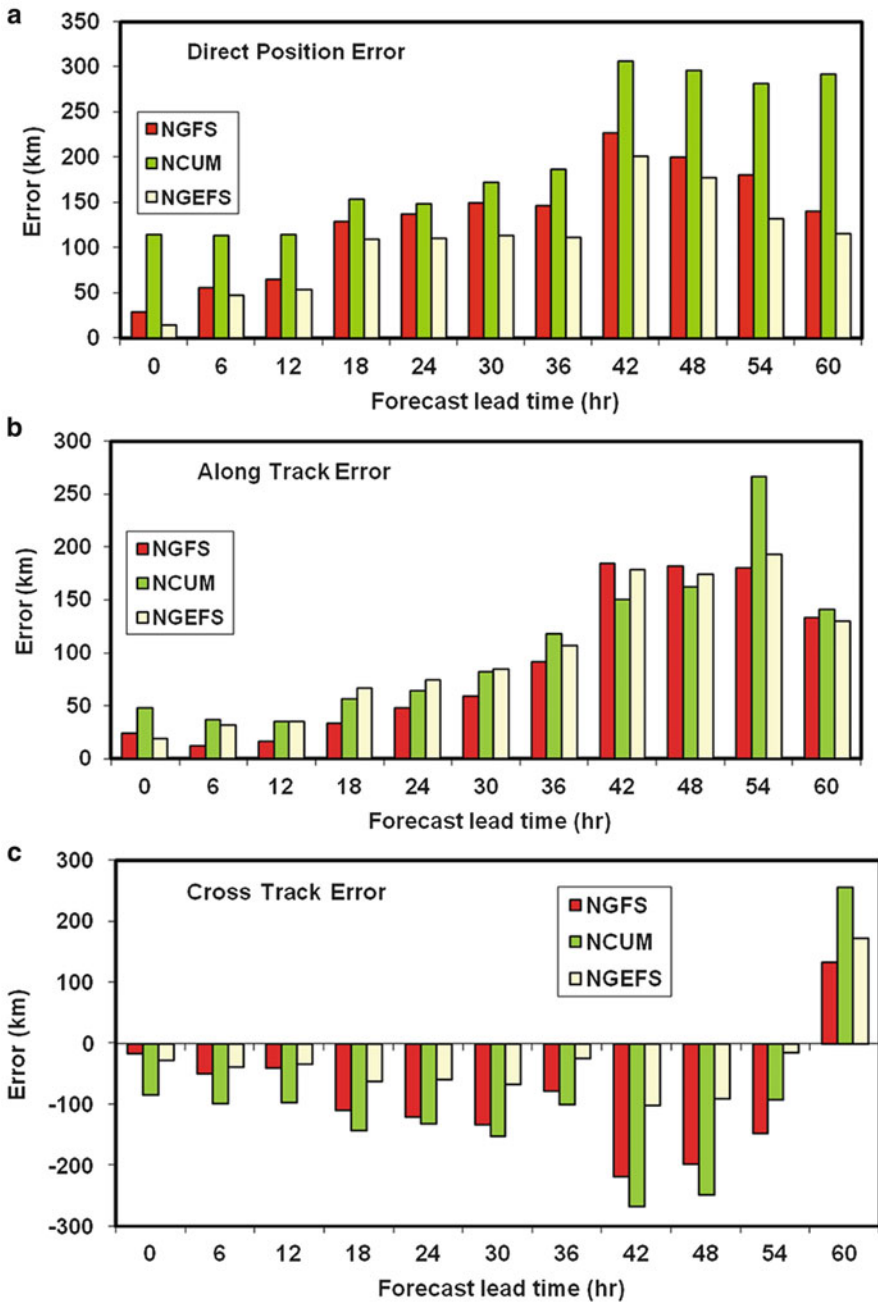
### 3.3.2 Error in Forecast Landfall Position and Time

The IMD reported that the SCS Helen crossed the coast between 0900 UTC of 22 November 2013 south of Machilipatnam in Andhra Pradesh at  $16.1^{\circ}$  N  $81.3^{\circ}$  E. Table 4 shows the landfall position and time errors based on all the available track forecasts. Forecasts show highest error in predicted landfall position based on 20th initial conditions. The predicted land fall time error varies from  $-3$  to  $+9$  h. Based on 21st and 22nd, NGEFS forecast shows least position error (48 and 24 km) and time error ( $+3$  and  $-3$  h). Both NCUM and NGFS have large position error.

### 3.4 'Lehar' Forecast Tracks (23–28 November 2013)

The observed and forecast tracks from NGFS, NCUM and NGEFS (mean and control) are presented based on initial conditions of 24–28 November 2013 in Fig. 6a–e. The forecast positions are shown at 6-h interval.

Forecasts based on 24, 25 and 26th initial conditions clearly suggest NGEFS mean track closely follows the observed track for most of the forecast period. The NCUM forecasts on the other hand show large deviation. NGFS forecasts too (to a



**Fig. 5** Average forecast track errors for SCS ‘Helen’ expressed in terms of (a) Direct position error (b) Along track (*lag* or *lead*) error and (c) Cross track (*left* or *right*) error

**Table 4** Forecast landfall position error for SCS Helen in the ESSO-NCMRWF global models (IMD reported landfall at 09 UTC of 22 November at location 16.1° N, 81.3° E)

Initial conditions	NGFS		NGEFS		NCUM	
	Position error (km)	Time error (h)	Position error (km)	Time error (h)	Position error (km)	Time error (h)
IC = 20112013	147	+9	154	+9	267	-3
IC = 21112013	131	+9	48	+3	39	+9
IC = 22112013	39	+3	24	-3	101	-3

('+' indicates delayed landfall, '-' indicates early landfall)

lesser extent) show some deviation from the observed track. Forecasts based on 27th and 28th also show wide dispersion from the observed track.

### 3.4.1 Forecast Track Errors (24–28 November 2013)

Forecast track errors are computed based on the 00 UTC TC positions from 24 to 28 November 2013 and average track errors are presented in Fig. 7a–c. The direct position error (DPE), Along track error (ATE; time lag/lead in movement) and Cross track error (CT; left/right error) are presented at 6-h interval up to 60 h. Positive (*negative*) values of ATE indicate that the movement of the TC in the forecasts is slower (*faster*) compared to the observations. On the other hand positive (*negative*) values of CTE indicate that forecast track is right (*left*) of the observed track.

The initial position errors in NGFS and NGEFS models are less than 50 km. The highest (lowest) initial position error of 72 km (19 km) is seen in NCUM (NGEFS). Up to 48 h all three models have comparable track errors with marginally higher errors in NGEFS. Beyond 48 h, NGEFS and NGFS forecasts show comparable errors while NCUM track shows very large error. The ATE values range from about less than 10 km (NGEFS) in the first 24 h to about 200 km in NCUM up to 72 h forecasts. The predominantly positive values of CTE in NCUM shown in Fig. 7c indicate the forecast TCs tracks lie to the right of observed tracks. NGFS (NGEFS mean) tracks lie to the left up to 24 h (60 h). Subsequently, both NGFS and NGEFS mean tracks lie to the left of observed tracks.

### 3.4.2 Error in Forecast Landfall Position and Time

The IMD reported that the VSCS Lehar crossed the coast between 0900 UTC of 28 November 2013 south of Machilipatnam in Andhra Pradesh at 15.9° N 81.1° E. Table 5 shows the landfall position and time errors based on all the available track forecasts. Forecasts show highest error in predicted landfall position and time based on 24 November 2013 initial conditions. Highest landfall position error of about 500 km is seen in NCUM forecast based on 24 November 2013. The predicted

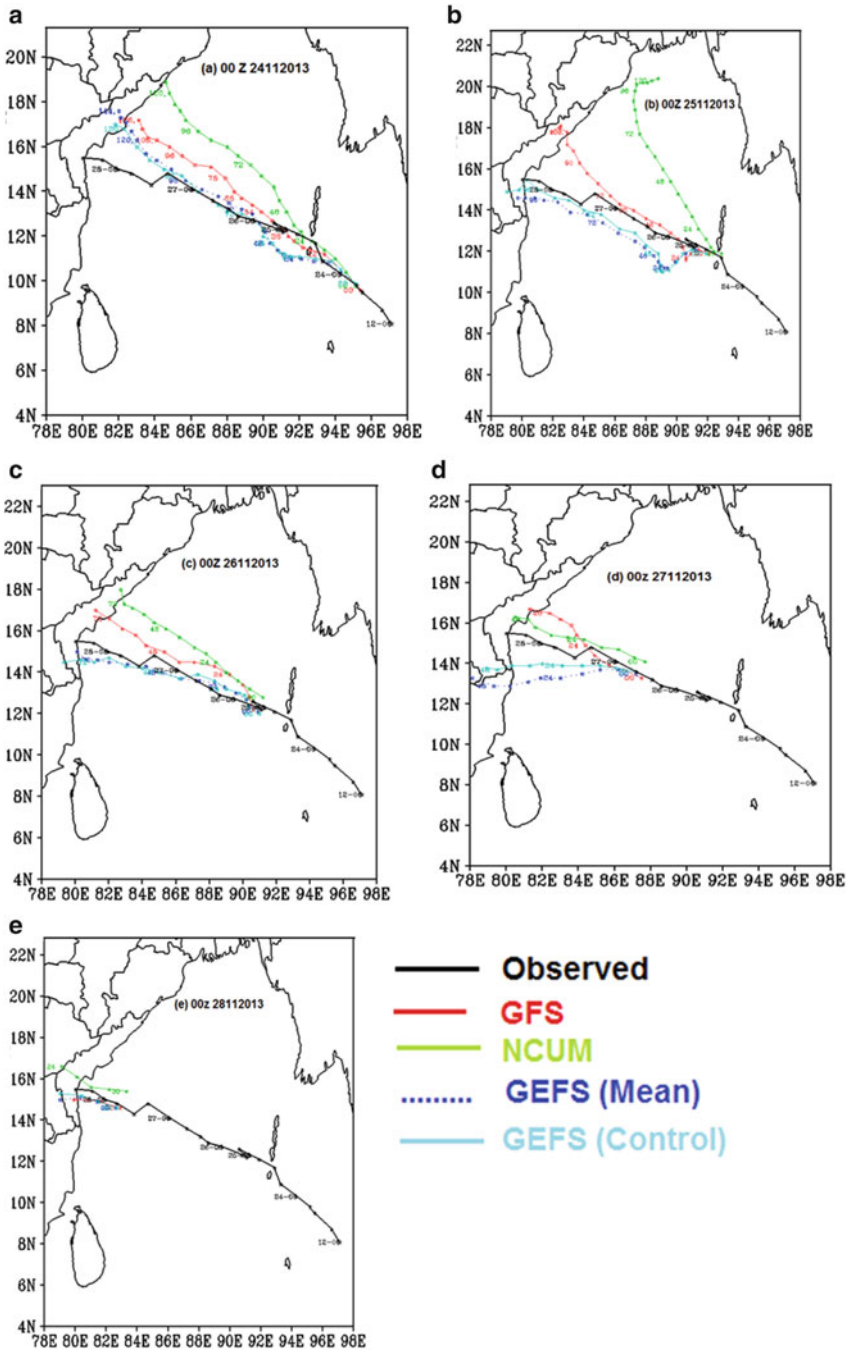
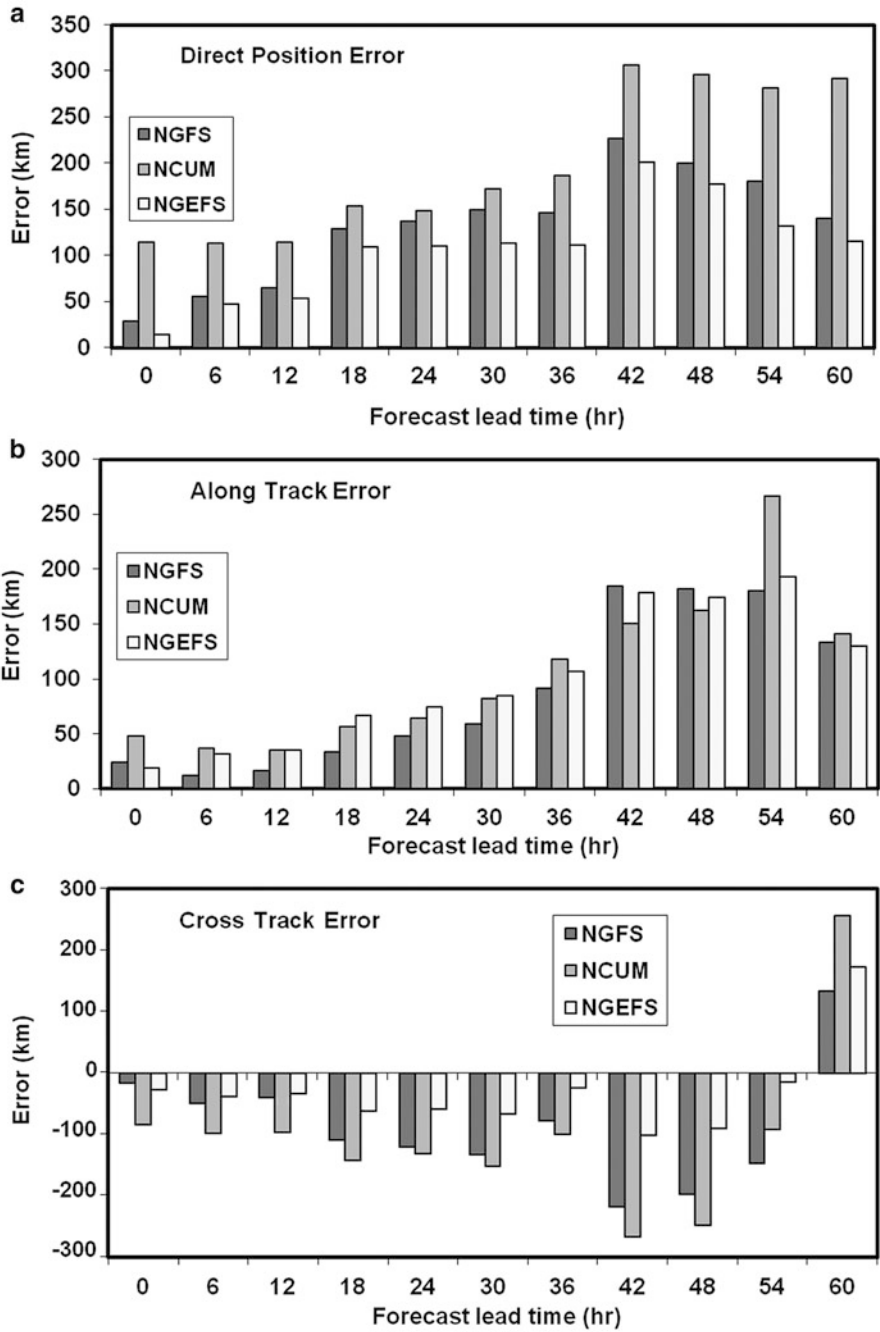


Fig. 6 Observed and forecasts tracks for VSCS 'Lehar' based on (a) 24thNov (b) 25th Nov (c) 26th Nov (d) 17th Nov and (e) 28th Nov 2014.



**Fig. 7** Average forecast track errors for VSCS 'Lehar' expressed in terms of (a) Direct position error (b) Along track (*lag* or *lead*) error and (c) Cross track (*left* or *right*) error

**Table 5** Forecast landfall position error for VSCS Lehar in the ESSO-NCMRWF global models (IMD reported landfall at 09 UTC of 28nd November at location 15.9° N, 81.1° E)

Initial conditions	NGFS		NGEFS		NCUM	
	Position error (km)	Time error (h)	Position error (km)	Time error (h)	Position error (km)	Time error (h)
IC = 24112013	257	+21	192	+27	499	+21
IC = 25112013	240	-3	148	+21	-	-
IC = 26112013	123	+15	154	+21	246	+15
IC = 27112013	154	+15	347	+9	35	+15
IC = 28112013	163	+9	123	+3	35	+3

('+' indicates delayed landfall, '-' indicates early landfall)

landfall time error varies from -3 to +27 h. NGFS and NGEFS show landfall position errors over 100 km in all the forecasts. On 27th and 28th NCUM forecasts show least landfall position errors of 35 km with landfall time errors of +15 h and +3 h, respectively.

### 3.5 'Madi' Forecast Tracks (6–12 December 2013)

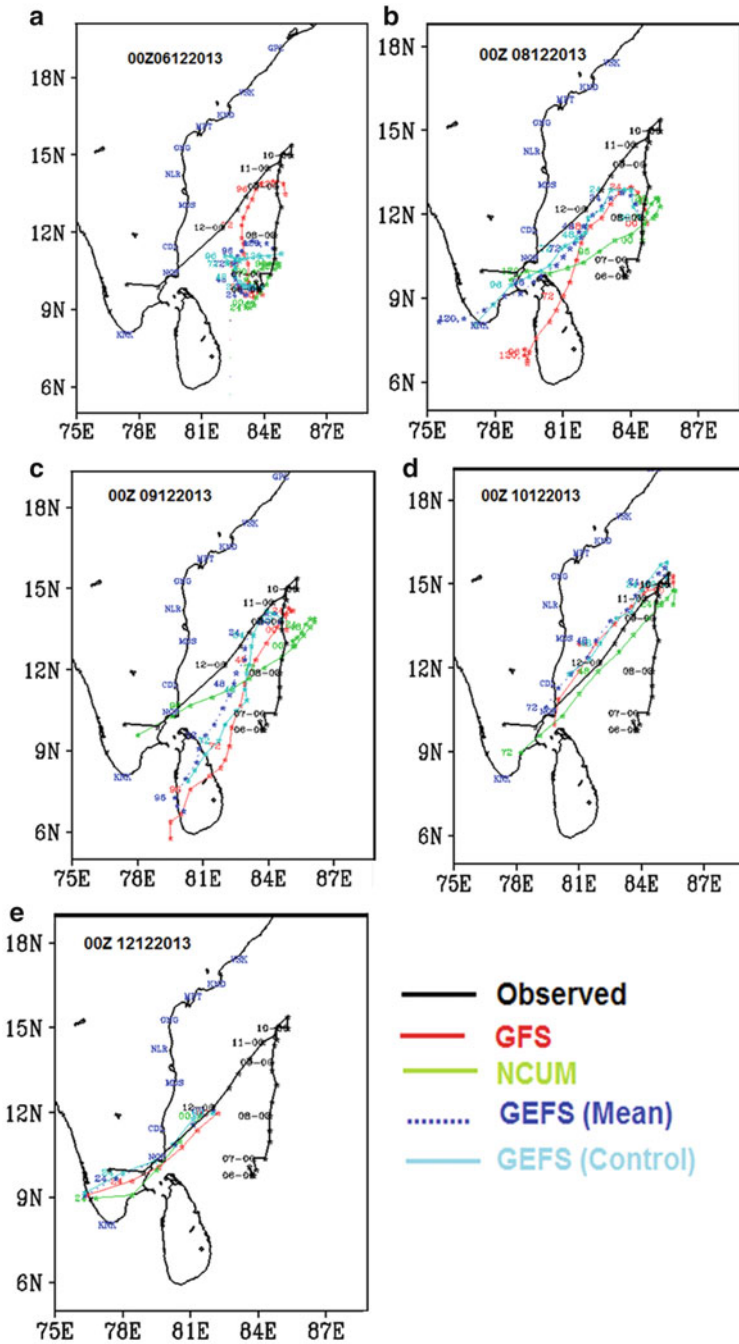
The observed and forecast tracks from NGFS, NCUM and NGEFS (mean and control) are presented based on initial conditions starting from 6, 8, 9, 10 and 12 December 2013 in Fig. 8a–e. The forecast positions are shown at 6-h interval. Forecasts based on 6 December 2013 initial conditions do not show clear movement and landfall of the cyclonic system (Fig. 8a). On 8 and 9 December 2013 the forecasts generally indicated northward movement in the beginning and then south-westwards (Fig. 8b, c). NGFS on both days (and NGEFS on 9 December 2013) suggested the TC would strike Sri Lanka coast, while NCUM consistently predicted the TC crossing Tamil Nadu. Tracks based on 10th, 11th (not shown) and 12th consistently showed TC would cross the Tamil Nadu coast near Nagapattinam (Fig. 8d, e).

#### 3.5.1 Forecast Track Errors (6–12 December 2013)

Forecast track errors are computed based on the 00UTC TC positions from of 6–12 December 2013 and average track errors are presented in Fig. 9a–c. DPE, ATE and CTE; are presented at 6-h interval up to 126 h.

The initial position errors in NGFS and NGEFS models are less than 50 km. The highest (lowest) initial position error of 86 km (13 km) is seen in NCUM (NGEFS). Up to 24 h NCUM has high DPE of about 100 km while NGFS and NGEFS mean show DPE increasing from under 50 km to over 100 km. From 24 to 78 h the NGFS (and NGEFS) DPE increase rapidly 463 km (434 km). Growth of DPE in NCUM is





**Fig. 8** Observed and forecasts tracks for VSCS ‘Madi’ based on 00 UTC of (a) 6th Dec (b) 8th Dec (c) 9th Dec (d) 10th Dec and (e) 12th Dec 2013.

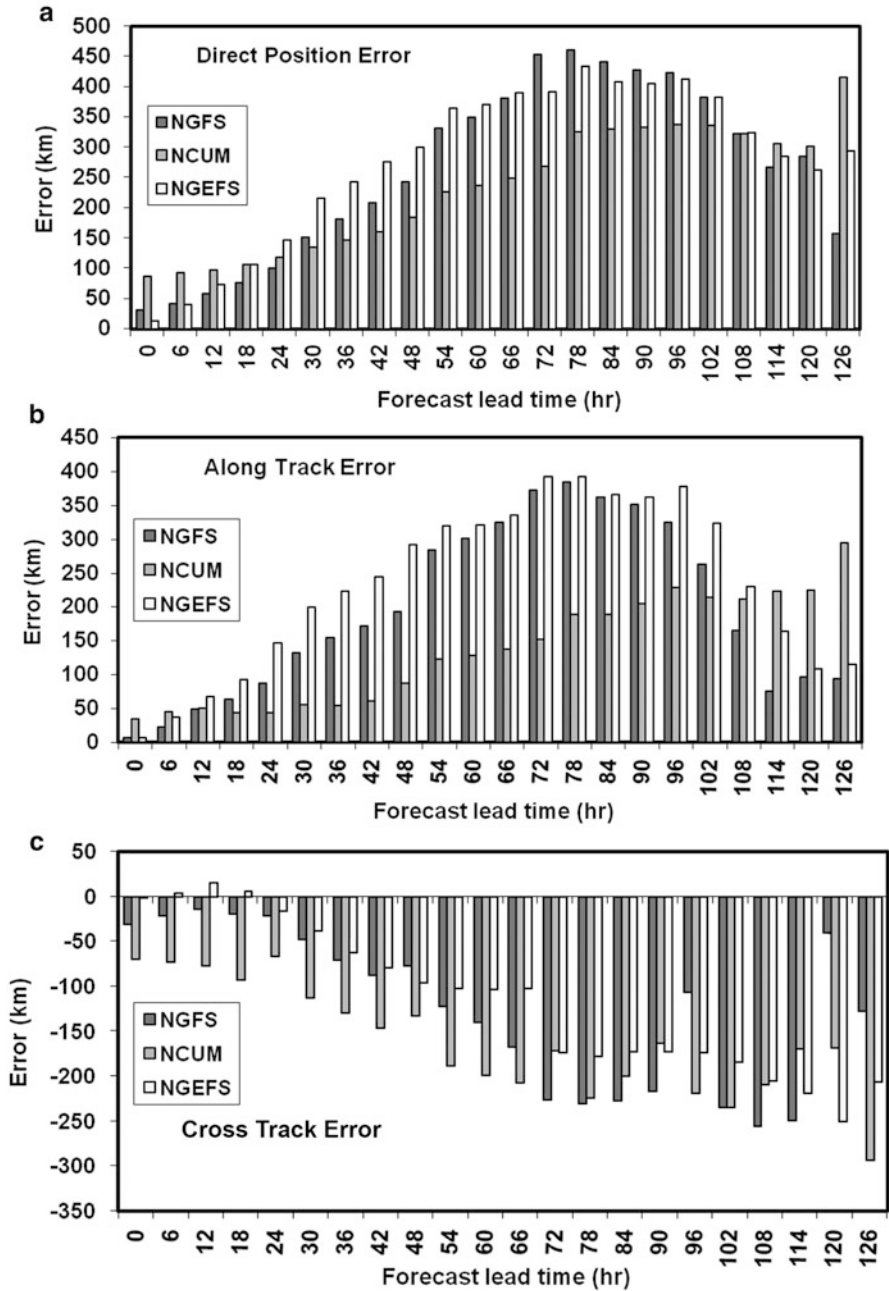


Fig. 9 Average forecast track errors for VSCS 'Madi' expressed in terms of (a) Direct position error (b) Along track (*lag* or *lead*) error and (c) Cross track (*left* or *right*) error

gradual in the 78 h with highest value of 325 km and 78 h. The DPE in NGFS and NGEFS gradually reduce after 78 h (after 102 h in NCUM). Similar pattern of error growth is seen for ATE (Fig. 9b). The predominantly negative values of CTE in NCUM shown in Fig. 9c indicate the forecast TCs tracks lie to the left of observed tracks. This is also evident from tracks based on 6–9 December 2013 (Fig. 8). The NGEFS mean track lies to the right of observed track on 10–12 December 2013. During the same period the NGFS and NCUM tracks show varying movement on both sides of the observed track.

### 3.5.2 Error in Forecast Landfall Position and Time

The IMD reported that the VSCS Madi crossed the Tamil Nadu coast near Tondi around 1700 UTC of 12 December 2013 at  $10.0^{\circ}$  N  $78.5^{\circ}$  E. Table 6 shows the landfall position and time errors based on the track forecasts from 8 to 12 December 2013 (track forecasts on 6 and 7 December 2013 did not show landfall). On 8 December NGFS shows a large time error of  $-41$  h with a landfall over Sri Lanka. NGFS and NGEFS tracks on 9 December 2013 showed landfall over Sri Lanka while NCUM showed landfall over Tamil Nadu coast with position error of 125 km. NGFS and NGEFS have large position error on 10 December 2013 while NCUM has least error in terms of time as well as distance. Similarly, on 11 and 12 December 2013 NCUM has least distance and time error in the predicted landfall.

## 3.6 Average Forecast Track Errors

The forecast track errors expressed in terms of average DPE for the five TCs of 2013 are shown in Fig. 10. The Figure also provides an intercomparison of the three models used for TC track prediction. The graphics shown clearly suggests that NGEFS has the least initial position error followed by NGFS (both below 50 km). The forecast position errors in NCUM are the lowest in 24, 48 and 72 h.

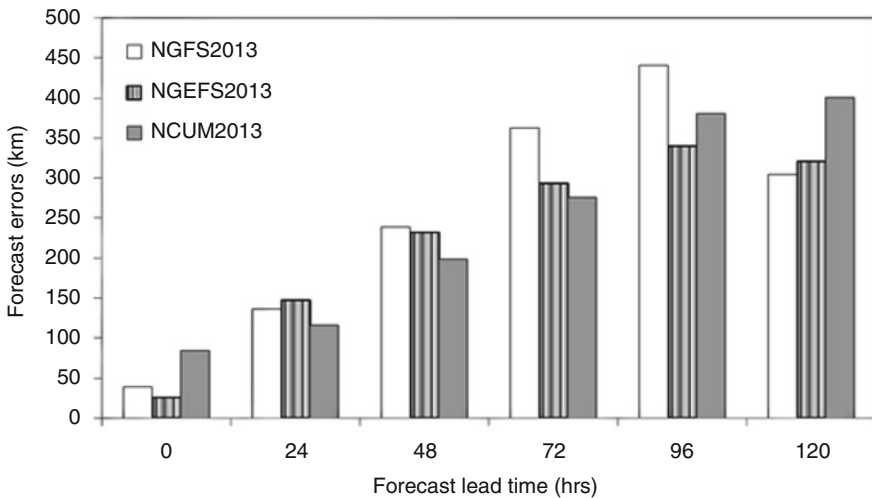
The initial position errors to a large degree determine the forecast position errors. An improvement in the accuracy of initial position in the model analysis is sure to improve the accuracy of forecast positions. Figure 11 shows the improvement in the analysis position in the NCMRWF model (NGFS). The consistent and sustained reduction in the initial position errors.

The improvement in NGFS system is attributed to TC relocation implemented in 2008. Further the assimilation of satellite radiances and other observations from non-conventional platforms has contributed towards reduction of initial position errors.

**Table 6** Forecast landfall position error for VSCS Madi in the ESSO-NCMRWF global models (IMD reported landfall at 1700 UTC of 12 December 2013 at location 10° N, 78.5° E near Tondi in Tamil Nadu)

Initial conditions	NGFS		NGEFS		NCUM	
	Position error (km)	Time error (h)	Position error (km)	Time error (h)	Position error (km)	Time error (h)
IC = 08122013	291	-41	110	+13	77	+7
IC = 09122013	403	-5	271	-5	125	+13
IC = 10122013	270	-5	218	+1	79	+1
IC = 11122013	171	-5	265	-11	171	-5
IC = 12122013	121	+1	104	+1	100	+1

(‘+’ indicates delayed landfall, ‘-’ indicates early landfall)



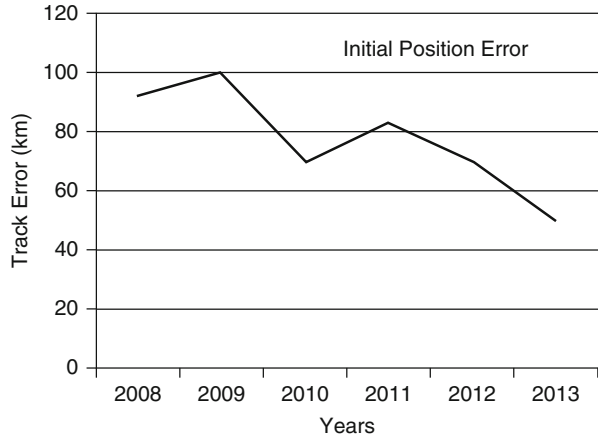
**Fig. 10** Average forecast track errors in the NCMRWF models during 2013

### 4 Summary and Conclusions

The 2013 TC track forecast verification presented in this study to report the performance of three modelling systems used at NCMRWF. Two deterministic systems namely NGFS and NCUM and an ensemble model NGEFS are used to provide TC track forecasts to IMD. The verification-cum-intercomparison results can be summarised as below.

1. The average DPEs for the 2013 TC cases show that NGEFS has the least initial position error followed by NGFS (both below 50 km). During 2008–2013 there is nearly 48 % reduction in the initial position errors in the NGFS.
2. The forecast position errors in NCUM are the lowest in 24, 48 and 72 h except in case of ‘Lehar’ and ‘Helen’.

**Fig. 11** Reduction in the initial position error of TCs in the NCMRWF global analysis system during recent years



3. The DPE computed for the NGFS and the NGEFS ensemble mean tracks indicate that the desired improvement in the ensemble mean track over the NGFS track prediction is evident only in case of ‘Viyaru’ and marginal in the two cases of ‘Phailin’ and ‘Helen’. In the two cases of Madi’ and ‘Lehar’ DPE in the NGFS forecast tracks are lower.
4. The CTE, ATE, landfall position errors and the errors in the predicted landfall time are all varying with TC cases, model and forecast lead time. Due to limited cases reported in this study it would be inappropriate to generalise and conclude on the performance of the models.

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