Improved prediction of cyclone *Phailin* (9–12 October 2013) with 4DVAR assimilation

This correspondence is a brief summary on the verification of National Centre for Medium Range Weather Forecasting (NCMRWF) model forecasts during the recent VSCS (very severe cyclonic storm) *Phailin* (9–12 October 2013). The study presents quantitative verification of forecast tracks and rainfall (after landfall). The real-time operational tropical cyclone (TC) track forecasts are based on NCMRWF Global Forecast System (NGFS) (T574L64) and NCMRWF Unified Model (NCUM). Both of these are state-of-the-art modelling systems with advanced parameterization schemes for sub-grid scale physical processes. Description of the model configurations implemented at NCMRWF can be found in Prasad *et al.*[1] for NGFS model and Rajagopal *et al.*[2] for NCUM model. The NGFS model uses a TC relocation algorithm for realistic representation of the location of the cyclone position in the initial conditions[3,4]. In NCUM, the initial position of the cyclone is captured in the analysis through four-dimensional variational data assimilation (4DVAR). The 4DVAR assimilation system prepares the analysis at observation time and implicitly generates flow-dependent background errors[5]. The NCUM is able to spin-up the TC without initialization, which can be attributed to combined impacts of improved model configuration, better data coverage (such as satellite data) and data assimilation technique. The data assimilated into the models include the special upper air observations from Visakhapatnam (0600 and 1800 UTC of 11 and 12 October 2013) and Regional ATOVS Retransmission Service (RARS). The verification presented in this study shows the improved track prediction and rainfall forecast (amount and distribution after landfall) in NCUM due to 4DVAR, demonstrating the importance of assimilation of observations at the most appropriate time.

Tracking of the TCs in the forecasts uses the TC Vital Database ('tcvitals'). The tcsvitals is an archive of Cyclone Message Files, which contain information such as cyclone location, intensity, horizontal wind and pressure structure, and depth of convection[6,7], created in real time by forecasting centres. These vitals are also used during the vortex relocation and bogusing process in the NGFS (ref. 3). The 'tcvitals' generated by the Joint Typhoon Warning Centre (JTWC) is used in this study for relocation as well as verification of the predicted cyclone positions.

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 and forecasts. A detailed account of the tracking algorithm is presented in Marchok[8]. Briefly, for TC, 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 cyclone position at each forecast hour. In order to avoid tracking weak, transient disturbances (either real or artifacts of model noise), two constraints have been added: (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 hPa contour interval.

Figure 1 *a* shows the cyclone tracks based on observed positions and positions of the cyclone in the initial conditions from 9 to 12 October 2013. NGFS model features an average initial position error of about 46 km, while the average initial position error in NCUM is 28 km. With initial error of 83 km in NGFS and 76 km in NCUM, both models have the highest initial position errors on

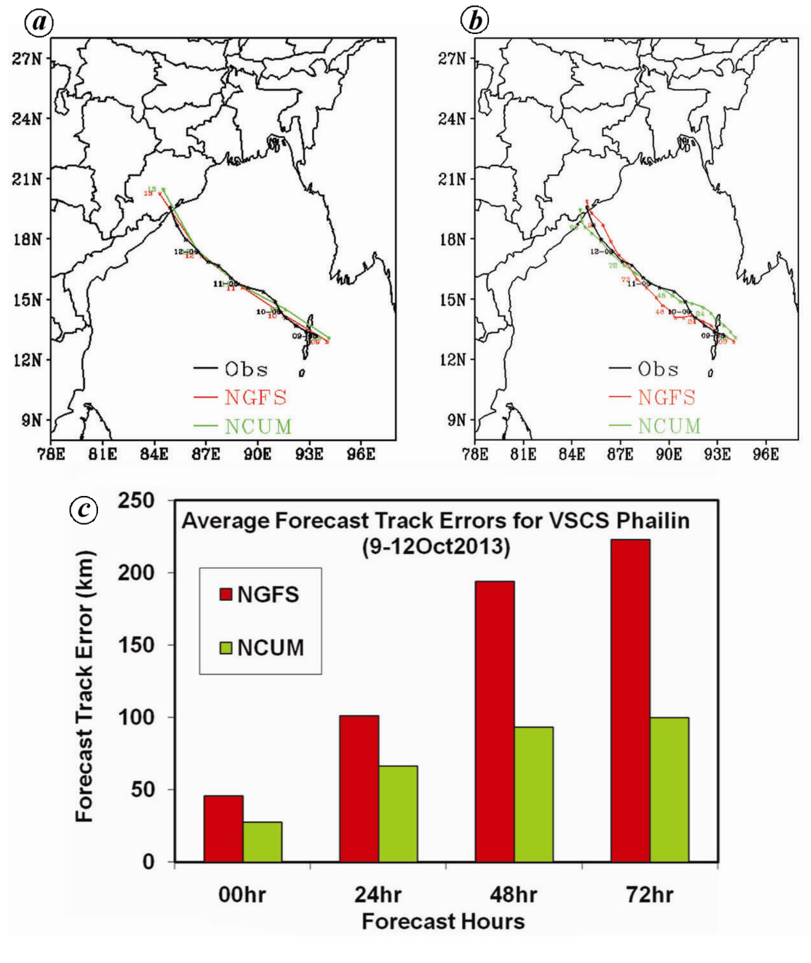

Figure 1. Track of VSCS *Phailin* in (***a***) observations and model initial analysis; (***b***) observations and forecasts based on 9 October 2013 and (***c***) average forecast track errors in GFS and NCUM during 9–12 October 2013.

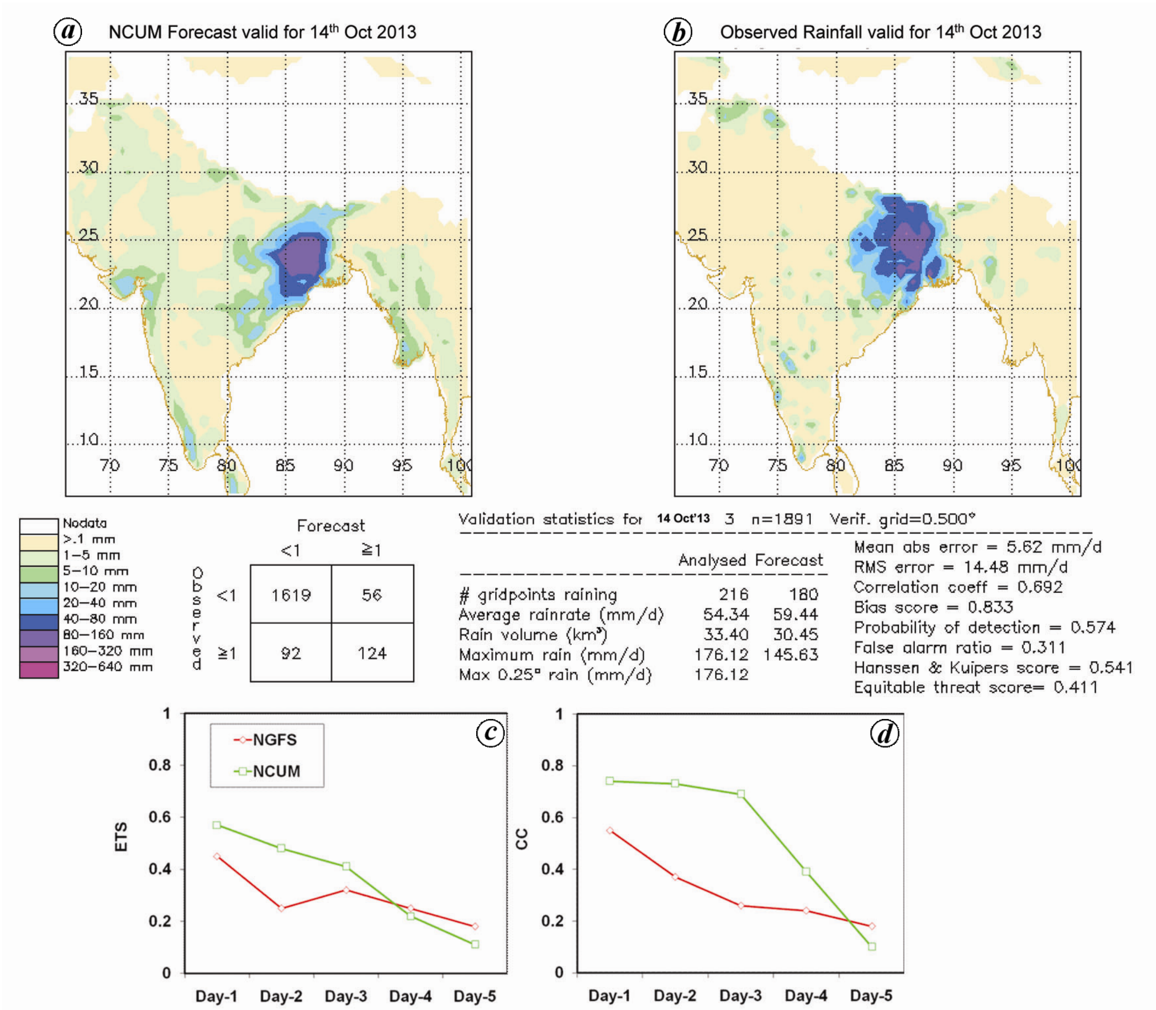

Figure 2. (***a***) Rainfall forecast and (***b***) observed skill of the two models at different lead times measured in terms of (***c***) Equitable Threat Score and (***d***) correlation coefficient.

9 October 2013. On 10–12 October both models have position errors less than 50 km. Forecast positions from the two models are shown in Figure 1 *b* based on 0000 UTC 9 October 2013. The forecasts indicate landfall over Andhra Pradesh (AP) and Odisha border. Similar tracks based on 10–12 October 2013 (not shown) consistently predicted landfall over the AP–Odisha border.

Forecast track errors are computed based on the JTWC reported cyclone positions from 0000 UTC of 9–12 October 2013. The average track errors are shown in Figure 1 *c*. NCUM has the lower position error at all lead times than that of NGFS. With reduction in the initial position error by 40% relative to NGFS, NCUM shows a reduction in forecast position errors by 34%, 52% and 55% in the 24, 48 and 72 h forecasts respectively, when compared against NGFS.

Additionally errors in the forecast cyclone position are also expressed in terms of cross-track (CT) error and along-track (AT) error. AT errors give an indication of whether a forecast TC movement is slow or fast. CT errors determine whether a model tends to recurve it too soon. A negative (positive) AT would indicate a slow (fast) bias. Similarly, a negative (positive) CT would indicate that forecast position lies to the left (right) of the observed track. The computed AT and CT values are given in Table 1. The negative AT values in all the forecasts are consistent with the slow movement and late landfall in the forecasts. However, NCUM shows lower magnitude of negative values (relative to NGFS) indicating relatively faster movement, thus closer to the observed track.

IMD reported landfall at 1500 UTC of 12 October 2013 at 19.1N 85.0E. Table 2 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. Both models have a delay of 15 h in the predicted landfall time based on 9 October 2013. The models predicted landfall on 13 October 2013. The NCUM forecasts based on 10–12 consistently predicted landfall at 0000 UTC of 13 October 2013, with persistent landfall time error of 3 h. NGFS on the other hand consistently showed landfall time error of 15 h, except with initial condition of 10 October 2013, when it showed landfall time error of 9 h.

The rainfall forecast verification is also presented for observed and forecast rainfall over eastern India after landfall of the cyclone. Figure 2 *a*, *b* shows observed and 72 h rainfall forecast in the

Table 1. Cross track (CT) and along track (AT) errors for VSCS *Phailin* in the NCMRWF global models

Models	Day-0	Day-1	Day-2	Day-3
NGFS (CT)	6	–33	–24	45
NCUM (CT)	17	30	25	18
NGFS (AT)	–47	–89	–192	–219
NCUM (AT)	–20	–54	–85	–106

AT '–ve' (+ve) slow (fast) moving; CT '–ve' (+ve) left (right) of observed track.

Table 2. Forecast landfall position and time error for VSCS *Phailin* in the ESSO-NCMRWF global models

	NGFS		NCUM	
Initial condition	Position error (km)	Time error (h)	Position error (km)	Time error (h)
09102013	31	+15	47	+15
10102013	84	+15	11	+3
11102013	42	+9	39	+3
12102013	115	+15	69	+3

IMD reported landfall at 1500 UTC of 12 October at 19.1N 85.0E; time error '+' denotes delay and '–' denotes early.

Table 3. RMSE (mm/day) in the rainfall forecasts valid for 0000 UTC of 14 October 2013 based on NGFS and NCUM at different lead times over eastern India

	Day-1	Day-2	Day-3	Day-4	Day-5
NGFS	58.6	62.2	68.8	74.5	85.5
NCUM	47.4	50.9	52.5	55.5	76.9

NCUM. The panels show the 24 h accumulated rainfall from 13 October 2013 (mm) along with detailed summary statistics. Based on the contingency table in the figure, observed and forecast raining grids (>1 mm/day), various scores are computed. NCUM forecasts have higher (lower) correlation and equitable threat score (ETS) (RMSE, bias and false alarm). Table 3 shows RMSE at all lead times, to clearly suggest high RMSE in NGFS forecasts. Similar verification for NGFS (not shown) shows relatively poor performance compared to NCUM forecasts. Figure 2 *c* shows the skill of the rainfall forecast by both models at all lead times. ETS and correlation coefficient show that NCUM has higher skill in predicted rainfall after landfall up to four days in advance, after which skill is generally low in both models.

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Received 20 December 2013; accepted 9 August 2014

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Elucidation of drug–DNA intercalation binding mode

The interactive study of small molecules with double-stranded DNA has been a topic of research for a few decades to get control gene expression. A number of drugs, especially those with planar moiety, bind to DNA and help suppress or depress the replication and transcription processes. The binding via intercalation mode is reversible in nature which makes it advantageous over covalent binding, keeping drug metabolism and harmful side effects in view[1]. The Van der Waals, stacking and electrostatic forces are mainly responsible for the intercalation mode of binding. The drugs like proflavine, ethidium bromide and actinomycin D contain planar aromatic rings responsible for intercalation[2]. Many biophysical and computational techniques are used to illustrate the intercalation mode of binding. Generally small molecules (ligands) show an absorption peak in the visible region in UV–visible absorption spectrum. Hypochromic effect and bathochromic